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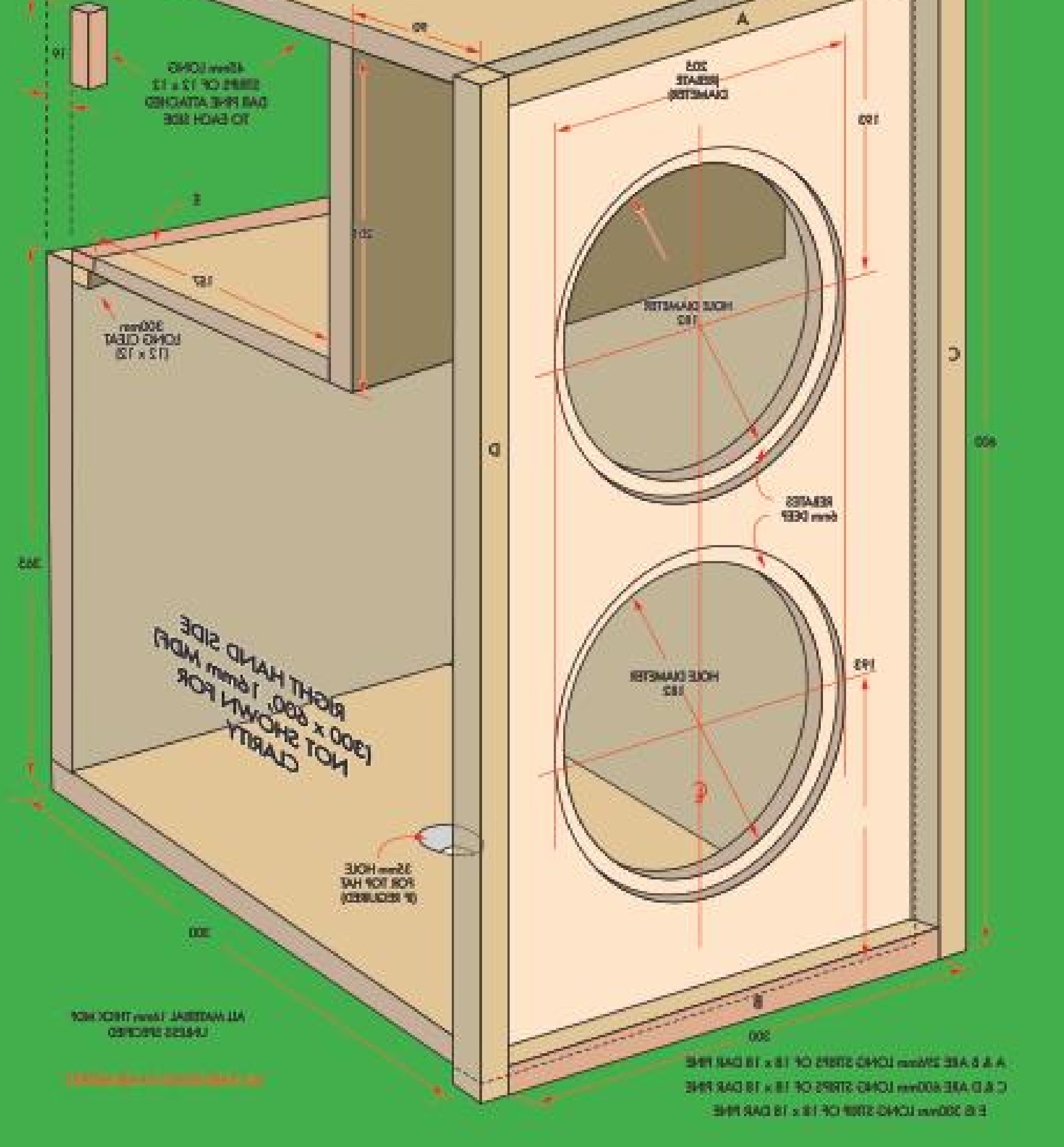

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For more information, go to: www.microchip.com/get/eupic32mz

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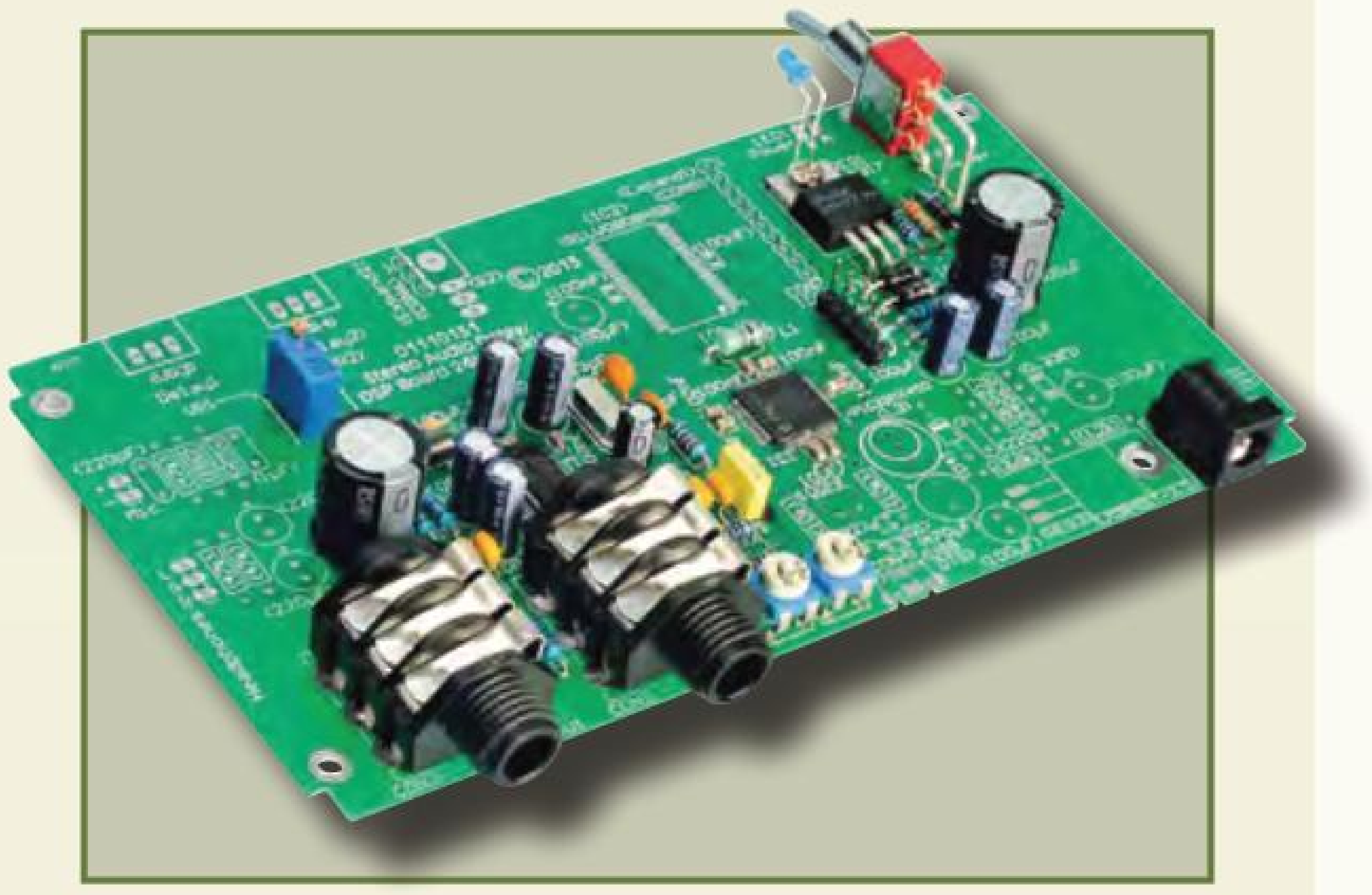

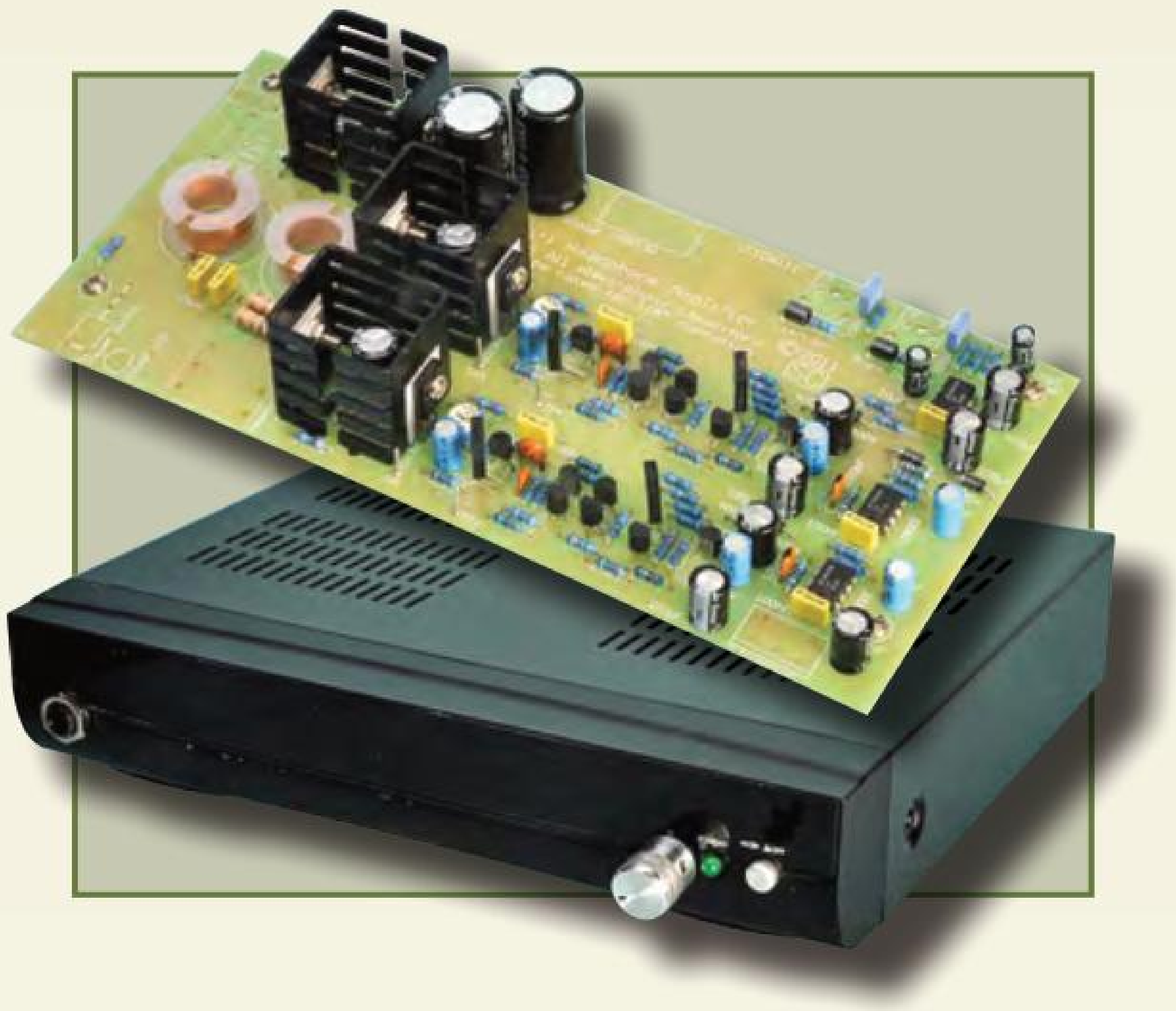

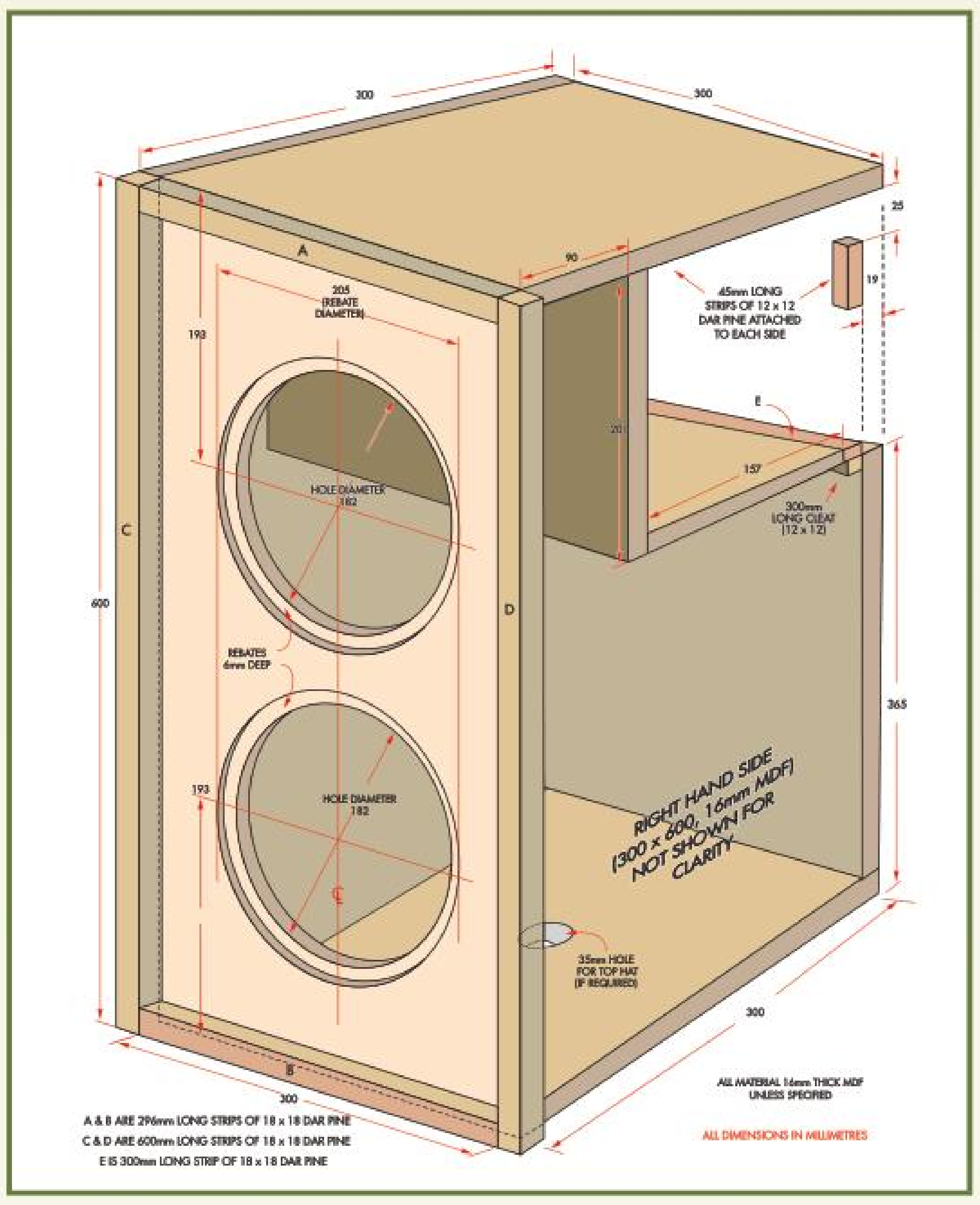
300
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205
(REBATE
DIAMETER)
45mm LONG
STRIPS OF 12 x 12
DAR PINE ATTACHED
TO EACH SIDE
19
193
E
C
HOLE DIAMETER
182
157
300mm
LONG CLEAT
(12 x 12)
600
D
REBATES
6mm DEEP
365
193
HOLE DIAMETER
182
RIGHT HAND SIDE
(300 x 600, 16mm MDF)
NOT SHOWN FOR
CLARITY
35mm HOLE
FOR TOP HAT
(IF REQUIRED)
300
B
300
ALL MATERIAL 16mm THICK MDF
UNLESS SPECIFIED
ALL DIMENSIONS IN MILLIMETRES
A & B ARE 296mm LONG STRIPS OF 18 x 18 DAR PINE
C & D ARE 600mm LONG STRIPS OF 18 x 18 DAR PINE
E IS 300mm LONG STRIP OF 18 x 18 DAR PINE

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Our March 2015 issue will be published on Thursday 5 February 2015, see page 72 for details.

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USB or Serial connection. Header cable for ICSP. Free Windows software. See website for PICs supported. ZIF Socket & USB lead extra. 16-18Vdc.
Kit Order Code: 3149EKT - £49.95
Assembled Order Code: AS3149E - £64.95
Assembled with ZIF socket Order Code: AS3149EZIF - £74.95

USB PIC Programmer and Tutor Board

This tutorial project board is all you need to take your first steps into Microchip PIC programming using a PIC16F882 (included). Later you can use it for more advanced programming. It programs all the devices a Microchip PICKIT2® can! You can use the free Microchip tools for the PICKit2™ and the MPLAB® IDE environment.
*Order Code: EDU10 - **£55.96***

ATMEL 89xxxx Programmer

Uses serial port and any standard terminal comms program. 4 LED's display the status. ZIF sockets not included. 16Vdc.
*Kit Order Code: 3123KT - **£28.95***
*Assembled Order Code: AS3123 - **£39.95***

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Go from complete beginner to burning a PIC and writing code in no time! Includes 49 page step-by-step PDF Tutorial Manual + Programming Hardware (with LED test section) + Windows Software (Program, Read, Verify & Erase) + a rewritable PIC16F84A. 4 detailed examples provided for you to learn from. PC parallel port. 12Vdc.
*Kit Order Code: 3081KT - **£16.95***
*Assembled Order Code: AS3081 - **£24.95***

PIC Programmer Board

Low cost PIC programmer board supporting a wide range of Microchip® PIC™ microcontrollers. Serial port. Free Windows software.
*Kit Order Code: K8076 - **£29.94***

PIC Programmer & Experimenter Board

PIC Programmer & Experimenter Board with test buttons and LED indicators to carry out educational experiments such as the supplied programming examples. Includes a 16F627 Flash Microcontroller that can be reprogrammed up to 1000 times. Software to compile and program your source code is included. Supply: 12-15Vdc.
*Kit Order Code: K8048 - **£23.94***
*Assembled Order Code: VM111 - **£39.12***

Controllers & Loggers

Here are just a few of the controller and data acquisition and control units we have. See website for full details. 12Vdc PSU for all units: Order Code 660.446UK £11.52

USB Experiment Interface Board

5 digital input channels and 8 digital output channels plus two analogue inputs and two analogue outputs with 8 bit resolution.
*Kit Order Code: K8055N - **£25.19***
*Assembled Order Code: VM110N - **£40.20***

2-Channel High Current UHF RC Set

State-of-the-art high security. 2 channel. Momentary or latching relay output rated to switch up to 240Vac @ 10 Amps. Range up to 40m. Up to 15 Tx's can be learnt by one Rx (kit includes one Tx but more available separately). 3 indicator LEDs. Rx: PCB 88x60mm, supply 9-15Vdc.
*Kit Order Code: 8157KT - **£49.95***
*Assembled Order Code: AS8157 - **£54.95***

Computer Temperature Data Logger

Serial port 4-channel temperature logger. °C or °F. Continuously logs up to 4 separate sensors located 200m+ from board. Wide range of free software applications for storing/using data. PCB just 45x45mm. Powered by PC. Includes one DS1820 sensor.
*Kit Order Code: 3145KT - **£19.95***
*Assembled Order Code: AS3145 - **£26.95***
*Additional DS1820 Sensors - **£4.95 each***

Remote Control Via GSM Mobile Phone

Place next to a mobile phone (not included). Allows toggle or auto-timer control of 3A mains rated output relay from any location

Mobile Phone NOT included

Most items are available in kit form (KT suffix) or pre-assembled and ready for use (AS prefix).

4-Ch DTMF Telephone Relay Switcher

Call your phone number using a DTMF phone from anywhere in the world and remotely turn on/off any of the 4 relays as desired. User settable Security Password, Anti-Tamper, **Rings** to Answer, Auto Hang-up and Lockout. Includes plastic case. 130 x 110 x 30mm. Power: 12Vdc.
*Kit Order Code: 3140KT - **£79.95***
*Assembled Order Code: AS3140 - **£94.95***

8-Ch Serial Port Isolated I/O Relay Module

Computer controlled 8 channel relay board. 5A mains rated relay outputs and 4 opto-isolated digital inputs (for monitoring switch states, etc). Useful in a variety of control and sensing applications. Programmed via serial port (use our new Windows interface, terminal emulator or batch files). Serial cable can be up to 35m long. Includes plastic case 130x100x30mm. Power: 12Vdc/500mA.
*Kit Order Code: 3108KT - **£74.95***
*Assembled Order Code: AS3108 - **£89.95***

Infrared RC 12–Channel Relay Board

Control 12 onboard relays with included infrared remote control unit. Toggle or momentary. 15m+ range. 112 x 122mm. Supply: 12Vdc/0.5A
*Kit Order Code: 3142KT - **£64.95***
*Assembled Order Code: AS3142 - **£74.95***

Audio DTMF Decoder and Display

Detect DTMF tones from tape recorders, receivers, two-way radios, etc using the built-in mic *or* direct from the phone line. Characters are displayed on a 16 character display as they are received and up to 32 numbers can be displayed by scrolling the display. All data written to the LCD is also sent to a serial output for connection to a computer. Supply: 9-12V DC (Order Code PSU375). Main PCB: 55x95mm.
*Kit Order Code: 3153KT - **£37.95***
*Assembled Order Code: AS3153 - **£49.95***

3x5Amp RGB LED Controller with RS232

3 independent high power channels. Preprogrammed or user-editable light sequences. Standalone option and 2-wire serial interface for microcontroller or PC communication with simple command set. Suitable for common anode RGB LED strips, LEDs and incandescent bulbs. 56 x 39 x 20mm. 12A total max. Supply: 12Vdc.
Kit Order Code: 8191KT - £29.95
Assembled Order Code: AS8191 - £39.95

Hot New Products!

Here are a few of the most recent products added to our range. See website or join our email Newsletter for all the latest news.

4-Channel Serial Port Temperature Monitor & Controller Relay Board

4 channel computer serial port temperature monitor and relay controller. Four inputs for Dallas DS18S20 or DS18B20 digital thermometer sensors (£3.95 each). Four 5A rated relay outputs are independent of sensor channels allowing flexibility to setup the linkage in any way you choose. Simple text string commands for reading temperature and relay control via RS232 using a comms program like Windows HyperTerminal or our free Windows application.
Kit Order Code: 3190KT - ***£84.95***
Assembled Order Code: AS3190 - ***£99.95***

40 Second Message Recorder

Feature packed non-volatile 40 second multi-message sound recorder module using a high quality Winbond sound recorder IC. Standalone operation using just six onboard buttons or use onboard SPI interface. Record using built-in microphone or external line in. 8-24Vdc powered. Change a resistor for different recording duration/sound quality. Sampling frequency 4-12 kHz. (120 second version also available)
Kit Order Code: 3188KT - ***£29.95***
Assembled Order Code: AS3188 - ***£37.95***

Bipolar Stepper Motor Chopper Driver

Get better performance from your stepper motors with this dual full bridge motor driver based on SGS Thompson chips L297 & L298. Motor current for each phase set using on-board potentiometer. Rated to handle motor winding currents up to 2 Amps per phase. Operates on 9-36Vdc supply voltage. Provides all basic motor controls including full or half stepping of bipolar steppers and direction control. Allows multiple driver synchronisation. Perfect for desktop CNC applications.
Kit Order Code: 3187KT - ***£39.95***
Assembled Order Code: AS3187 - ***£49.95***

Video Signal Cleaner

Digitally cleans the video signal and removes unwanted distortion in video signal. In addition it stabilises picture quality and luminance fluctuations. You will also benefit from improved picture quality on LCD monitors or projectors.
Kit Order Code: K8036 - ***£24.70***
Assembled Order Code: VM106 - ***£36.53***

Motor Speed Controllers

Here are just a few of our controller and driver modules for AC, DC, Unipolar/Bipolar stepper motors and servo motors. See website for full details.

DC Motor Speed Controller (100V/7.5A)

Control the speed of almost any common DC motor rated up to 100V/7.5A. Pulse width modulation output for maximum motor torque at all speeds. Supply: 5-15Vdc. Box supplied. Dimensions (mm): 60Wx100Lx60H.
Kit Order Code: 3067KT - ***£19.95***
Assembled Order Code: AS3067 - ***£27.95***

Bidirectional DC Motor Speed Controller

Control the speed of most common DC motors (rated up to 32Vdc/10A) in both the forward and reverse direction. The range of control is from fully OFF to fully ON in both directions. The direction and speed are controlled using a single potentiometer. Screw terminal block for connections.
Kit Order Code: 3166v2KT - ***£23.95***
Assembled Order Code: AS3166v2 - ***£33.95***

Computer Controlled / Standalone Unipolar Stepper Motor Driver

Drives any 5-35Vdc 5, 6 or 8-lead unipolar stepper motor rated up to 6 Amps. Provides speed and direction control. Operates in stand-alone or PC-controlled mode for CNC use. Connect up to six 3179 driver boards to a single parallel port. Board supply: 9Vdc. PCB: 80x50mm.
Kit Order Code: 3179KT - ***£17.95***
Assembled Order Code: AS3179 - ***£24.95***

Computer Controlled Bi-Polar Stepper Motor Driver

Drive any 5-50Vdc, 5 Amp bi-polar stepper motor using externally supplied 5V levels for STEP and DIRECTION control. Opto-isolated inputs make it ideal for CNC applications using a PC running suitable software. Board supply: 8-30Vdc. PCB: 75x85mm.
Kit Order Code: 3158KT - ***£24.95***
Assembled Order Code: AS3158 - ***£34.95***

AC Motor Speed Controller (600W)

Reliable and simple to install project that allows you to adjust the speed of an electric drill or 230V AC single phase induction motor rated up to 600 Watts. Simply turn the potentiometer to adjust the motors RPM. PCB: 48x65mm. Not suitable for use with brushless AC motors.
Kit Order Code: 1074KT - ***£15.95***
Assembled Order Code: AS1074 - ***£23.95***

See website for lots more DC, AC and stepper motor drivers!

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Features 2 input channels - high contrast LCD with white backlight - full auto set-up for volt/div and time/div - recorder roll mode, up to 170h per screen - trigger mode: run - normal - once - roll ... - adjustable trigger level and slope and much more.
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Order Code: HPS50 - ~~***£289.96***~~ ***£204.00***

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Win a Microchip Multimedia Expansion Board & PIC32 Starter Kit

EVERYDAY PRACTICAL ELECTRONICS is offering its readers the chance to win a Microchip Multimedia Expansion Board (DM320005) along with a PIC32 Starter Kit (DM320001).

The Multimedia Expansion Board (MEB) with the PIC32 Starter Kit provides users with an integrated, yet flexible solution for the development of high-impact user interfaces. The board comes with a 3.2-inch colour TFT touch-screen QVGA display, an onboard FCC-certified Wi-Fi module, a 24-bit stereo audio codec, a three-axis accelerometer, a joystick and a microSD memory card slot. Simply connect any DM320001, DM320003-2, DM320004, DM330012 or DM240012 Starter Kit to the MEB and you're ready to develop, program and debug code for the user interface features. Demo software for the MEB can be downloaded from the Microchip Application Library, including software for the joystick, accelerometer and more.

The PIC32 Starter Kit provides the easiest and lowest-cost method to experience the PIC32 microcontroller for the first time. From the over 35 source code examples to the getting started project, users quickly learn how to use Microchip's 32-bit family of microcontrollers and development tools. The kit includes everything needed to write, program, debug, and execute code on a high performance PIC32 microcontroller.

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HOW TO ENTER

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The closing date for this offer is 28 February 2015

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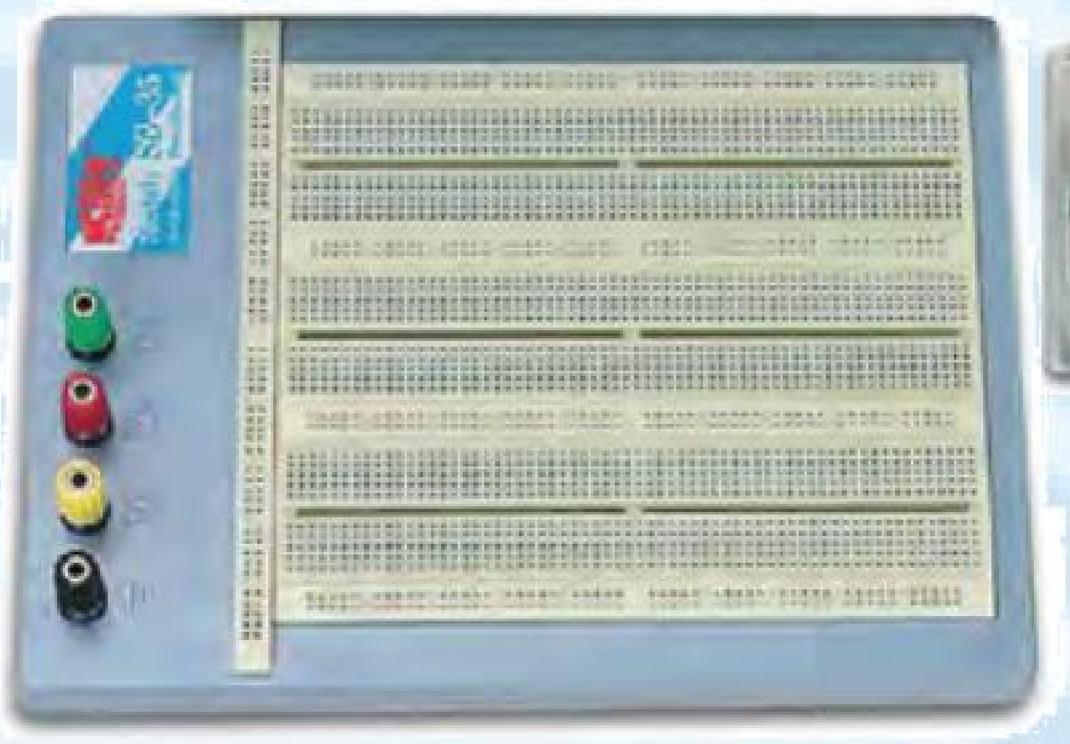

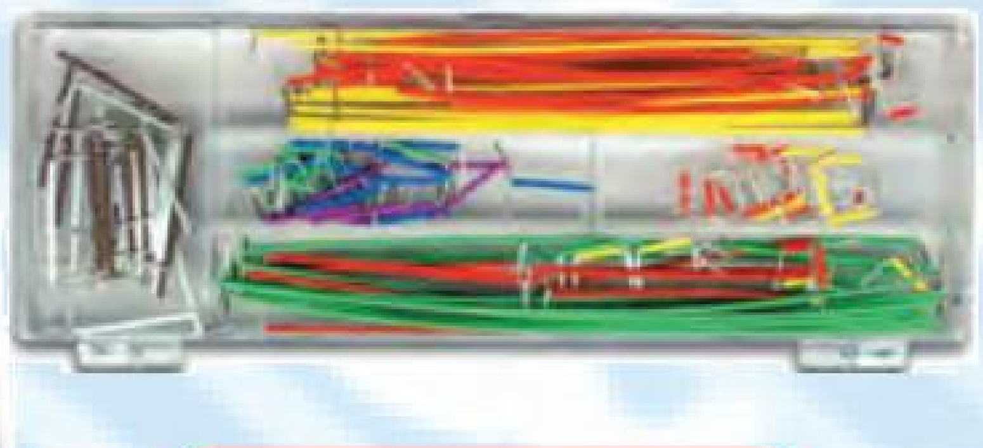

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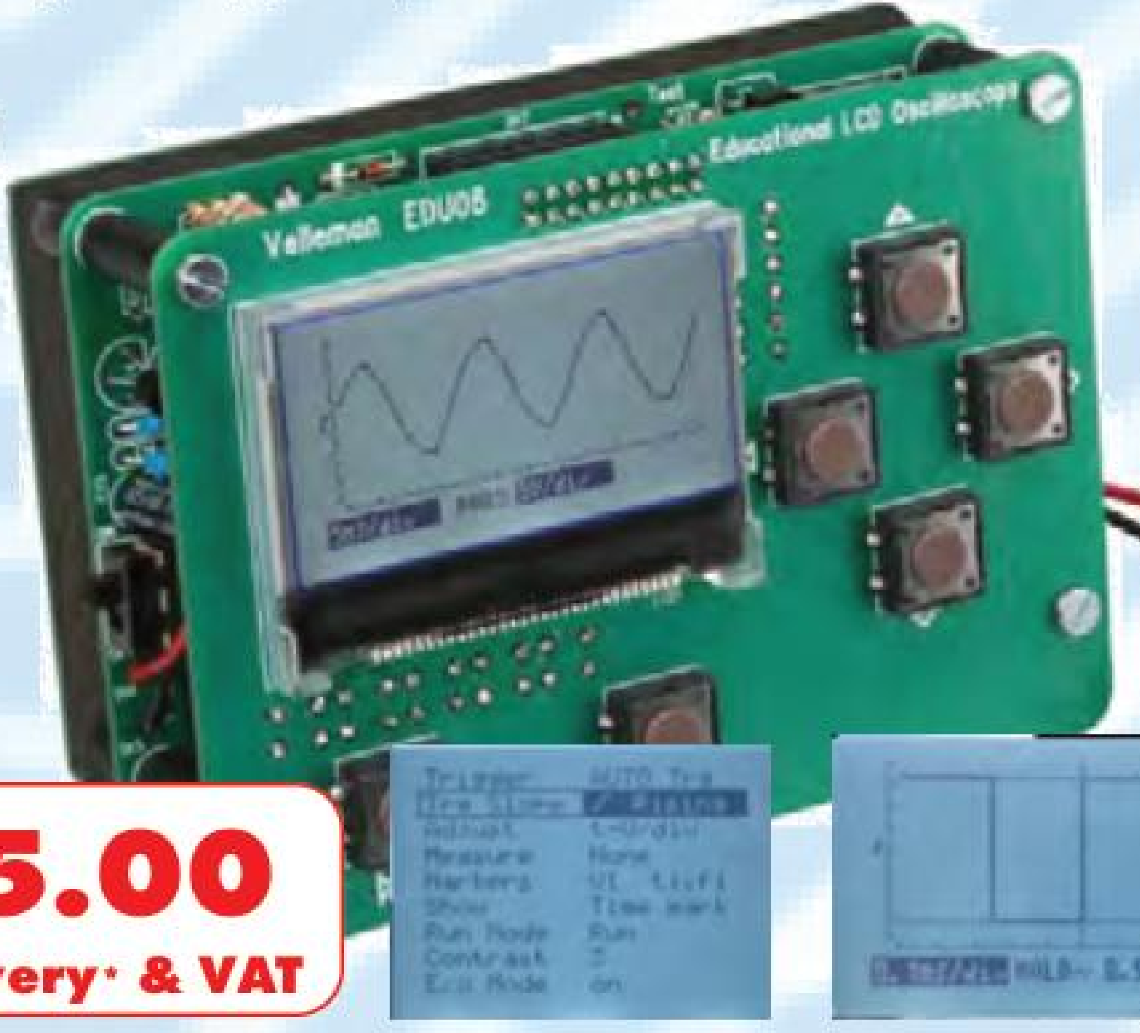
Max Sample Rate:
1ms/s repetitive signal,
100ks/s real time signal
Dim: 80 x 115 x 40mm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EVERYDAY PRACTICAL ELECTRONICS

Happy New Year!

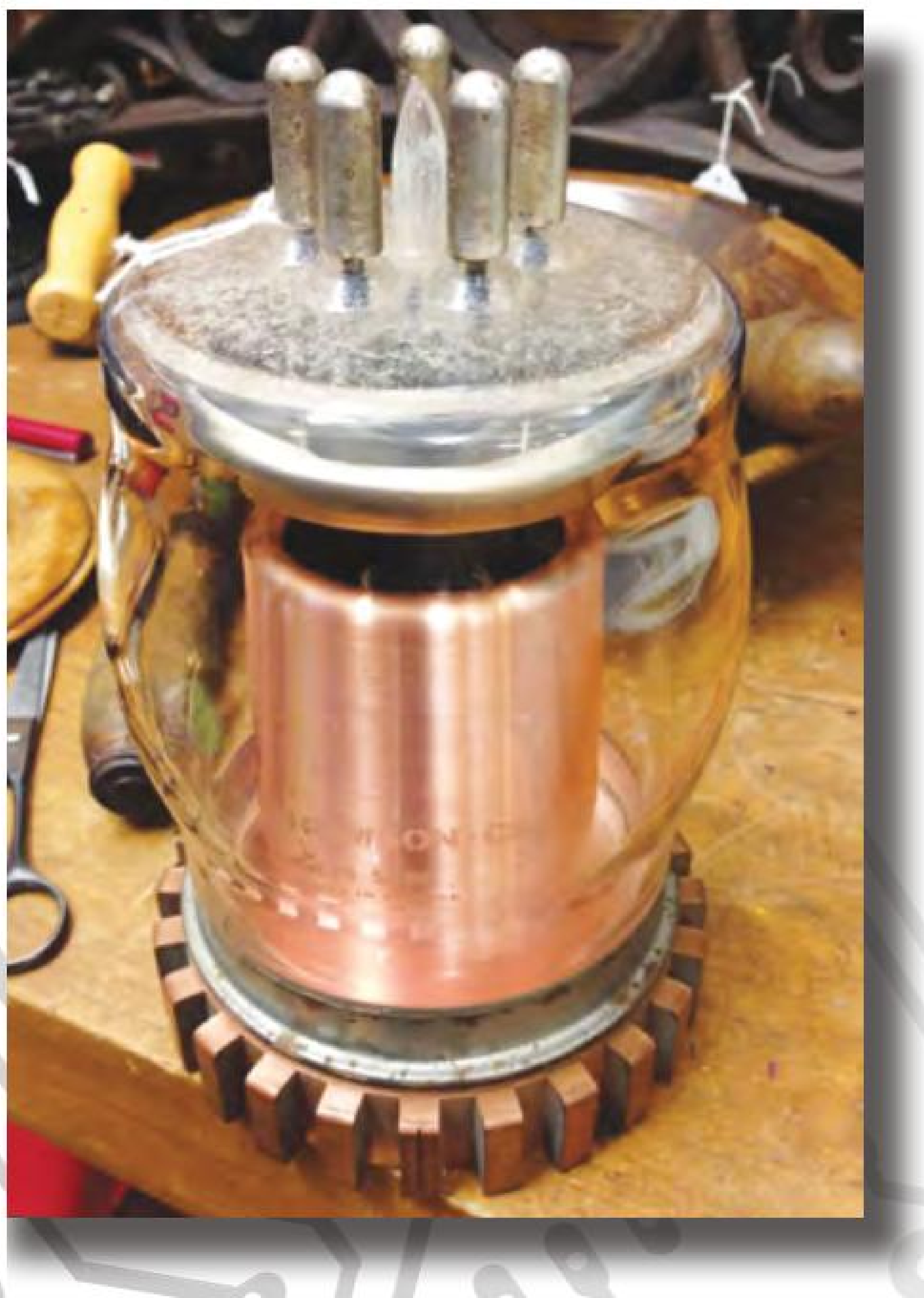
A warm welcome to the first *EPE* issue of the year. 2014 was not just a great year for your favourite electronics magazine, but it was also our 50th birthday. That and *Teach-In 2014* on the Raspberry Pi make it a tough act to follow, but this month we hit the ground running with the first part of *Teach-In 2015*! It's a great start to a fascinating new series on discrete linear design that I have been looking forward to for many months – I hope you enjoy and learn from it as much as me.

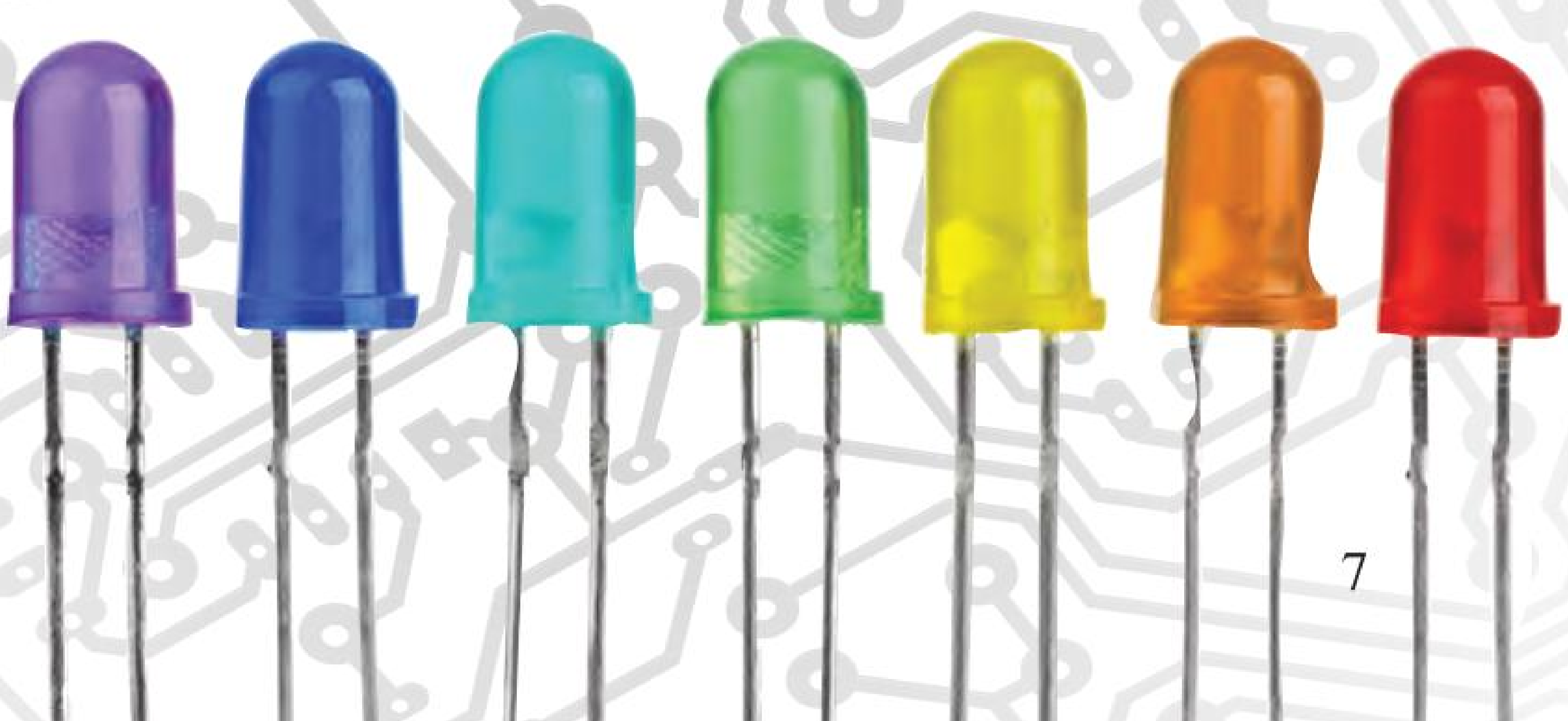
Time traveller's tetrode?

I thought I'd share with you a little piece of electronic 'what on earth is that?' fun, which I spied in my local flea market. It's one of those things that you just know given half a chance would be used in a De Lorean as a 'flux capacitor' substitute, or possibly in a TARDIS as a sonic screwdriver booster… or perhaps built into something even more imaginative by our very own 'Cool Beans' Max!

Thomson, the French manufacturer, thoughtfully labeled the device – TH 5186 – and slightly to my surprise Google identified it immediately. However, I was a little disappointed to discover that it won't aid time travel, but it is handy if you need to switch half a megawatt at a very high voltage. Apparently it is a tetrode used in MRI scanners, and will switch pulses of up to 5A at plate voltages up to 100kV. As you can imagine, this requires some pretty serious thermal management; so, as well as dissipating heat with the impressive copper heatsink at the bottom, this part normally operates submerged in a tank of oil for cooling and electrical insulation.

Despite it's lack of sci-fi credentials, it is a rather beautiful object that would make a great paperweight!





NEWS

A roundup of the latest Everyday News from the world of electronics

Object-based sound from Dolby – report by Barry Fox

Domestic Atmos

While most homes are turning their backs on multi-channel, multi-speaker sound, Dolby Labs is promoting a home version of Atmos, the cinema sound system that uses more speakers to add height to conventional 5.1 or 7.1 horizontal surround.

Atmos is different from conventional stereo or surround because it is 'object-based'. Instead of the traditional method of spreading a total sound field over a few loudspeakers, object-based coding treats individual sounds, such as musical instruments, voices or a jet plane, as 'objects', which are sent to target speakers or groups of speakers. Metadata buried in the audio signal controls a 'rendering' system which moves the sounds between speakers to create a sound trajectory – for instance, so that movement of a jet's sound matches movement of the plane on screen.

Tuned speakers

Dolby's Scott Harris says (in company patents) that he believes the 'ideal' way to reproduce music in high fidelity is to send sounds to 'tuned' speakers – eg, violins from speakers which are 'closely tuned to violins'.

However, a common problem with conventional home audio is 'sweet spots', which also affects object-based audio, says Dolby's Brett Crockett. He writes: 'when a listener moves away from the ideal listener location assumed by an object-based audio rendering system, the audio… perceived by the listener is spatially distorted.'

Audio problem, optical solution

The proposed solution is to visually track listeners in the room, using a camera device such as an Xbox Kinect or Playstation Eye. The audio is then rendered to suit 'the position and/or size of each listener'.

Dolby says the system should compensate for even small movements away from the sweet spot. If 'the listener moves from the center of a couch to the left side of the couch, nearer to the left speaker, the system would detect this movement and compensate the level and delay of the output of the left and right speaker'.

The camera also compensates when it detects a 'small person… assumed… to be a child' or 'a larger person… identified… as an elderly person with hearing loss' and 'dynamically renders the audio'.

The visual tracking system could also identify 'that the child is dancing to the music' or identify 'that a person sitting in a chair or couch has fallen asleep, and… gradually turn down the audio playback level or turn off the audio.'

Practical installation issues

One of the biggest problems with home Atmos, which Dolby's own promotional video admits, is persuading home owners to cut holes in their ceilings to house extra speakers. The proposed solution is to use floor speakers which fire upwards and bounce sound off the ceiling. KEF and Onkyo already sell reflective speakers.

One of Dolby's earliest patent filings on adding height to conventional horizontal surround, from Christophe Chabanne in September 2008, harks back to the early days of surround sound, when audio pioneer David Hafler derived signals for rear channels by extracting out-of-phase information from the front channels. Dolby's filing suggests mounting height speakers above the front pair of a 7.1 system, and feeding them with out-of-phase information extracted from the feeds to the rear side speakers.

A simple, but unavoidable problem is that all living rooms are different, so positioning the speakers so that they bounce sound to the correct listening area, and don't intrude on everyday living, is no mean challenge. For several months Dolby has been steadfastly ducking my requests for a demo.

Epson's new approach to printer ink pricing

Tired of feeding your ink jet printer with over-priced ink or risking trouble from cheap counterfeit cartridges?

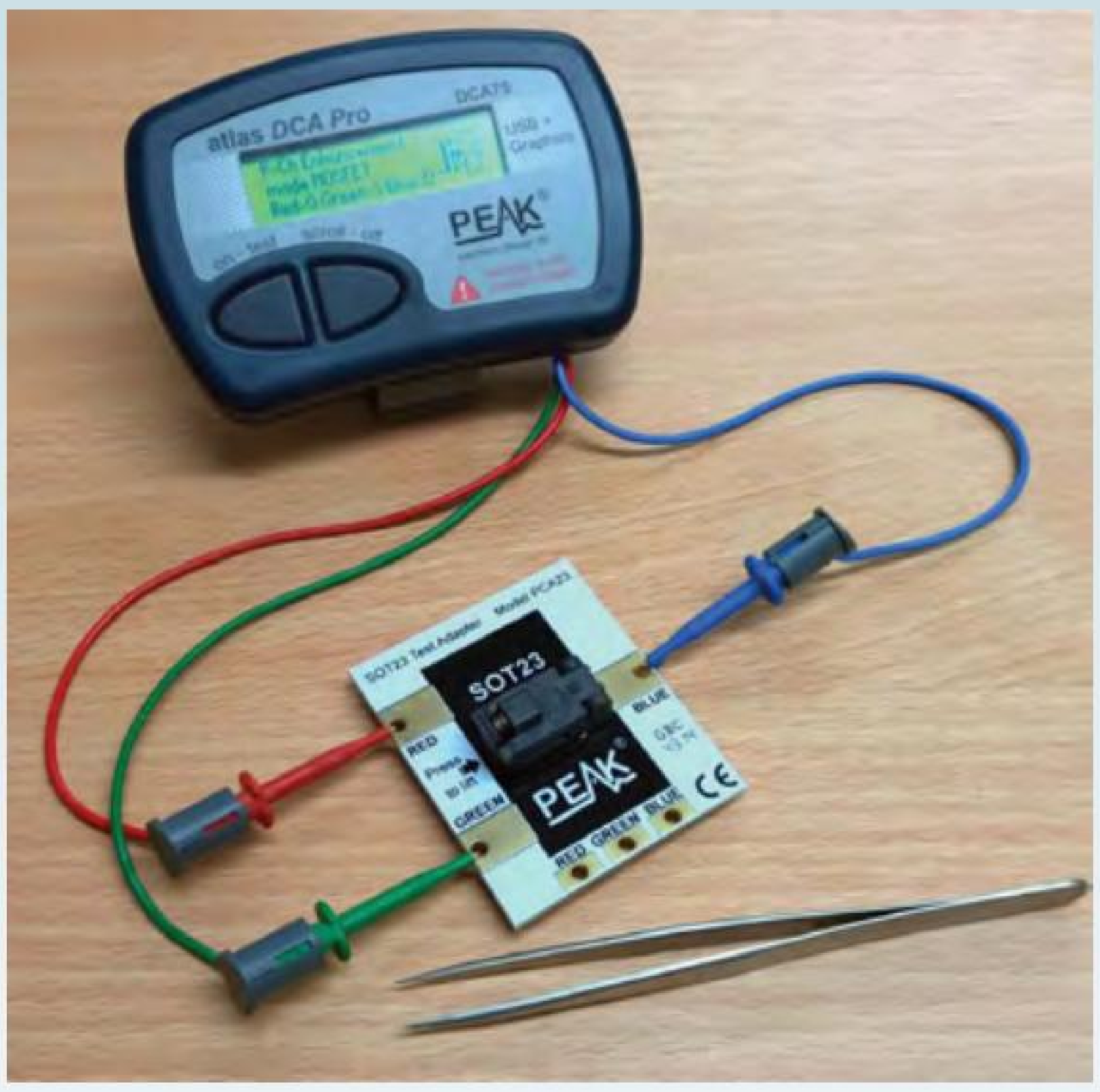
For the last four years, Epson has been quietly test marketing a printer in Russia that reverses the razor/razor blade business model. Instead of charging next to nothing for the printer and trying to make money from over-priced ink, Epson's new EcoTank printers are sold for a realistic price (£250 for the L355 All-in-One and £330 for the L555 with fax), and come with a large ink tank on the side. This tank gives users 'virtually limitless printing for up to two years'; 4000 mono pages and 6500 colour. When the ink tank finally

In Russia, Epson are testing a new way to price printing – realistic hardware prices and 'cheap' ink. Pictured above with its large ink tanks on the side, Epson's L355 printer runs dry, the user pays £8 each for four 70 ml bottles of black, cyan, magenta and yellow ink, and squirts it into the tank.

Why test market in Russia? Says Neil Wilson, Business Manager, Epson UK: 'The market there is special. Most homes are spending their money on essentials like food, and printers are used mainly by small businesses.'

I have been trying an Eco-Tank and apart from minor problems such as software conflicts with a previously installed Epson scanner, it looks as if the claims are justified. (Of course I can't confirm the two-year part of the claim yet.)

Peak launches innovative SOT23 test adapter



Peak Electronics has released an elegant solution to testing SOT23 parts. The test adapter is designed to complement Peak's DCA55 or DCA75 semiconductor tester. It's extremely easy to use thanks to the special spring-loaded SOT23 socket assembly. The SOT23 part under test is gently and securely held against gold plated sprung contacts with a controlled contact force.

The adapter is designed to look like a giant SOT23 part, so it's easy to visualise the pinout of the part inside when using the DCA55 or DCA75.

The unit is supported on four non-slip feet which also serve to keep the unit slightly raised from your work surface, allowing for easier connections using micro-hooks or croc clips. The large gold-plated pads are also great for multimeter probing. Further details are available at: **www.peakelec.co.uk**

Fun with Parallax

Parallax have added several keenly-priced project-enhancing products to their web-based store.

RGB LED

The WS2812B RGB LED module has a special LED on board that contains three separate LEDs – red, green, and blue – as well as a smart control IC that can individually drive each LED. Each colour has 256 intensity levels which allows the module to produce 24-bit colour, or more than 16 million colours. Each module is instructed by using a special serial protocol that allows many modules to be daisy-chained together so that one microcontroller can control the whole lot – with a single data signal. Any number of these modules can be chained together by connecting one module's data-out (DO) pin to another's data-in (DI) pin. More details available at: **www.parallax.com/product/28085**

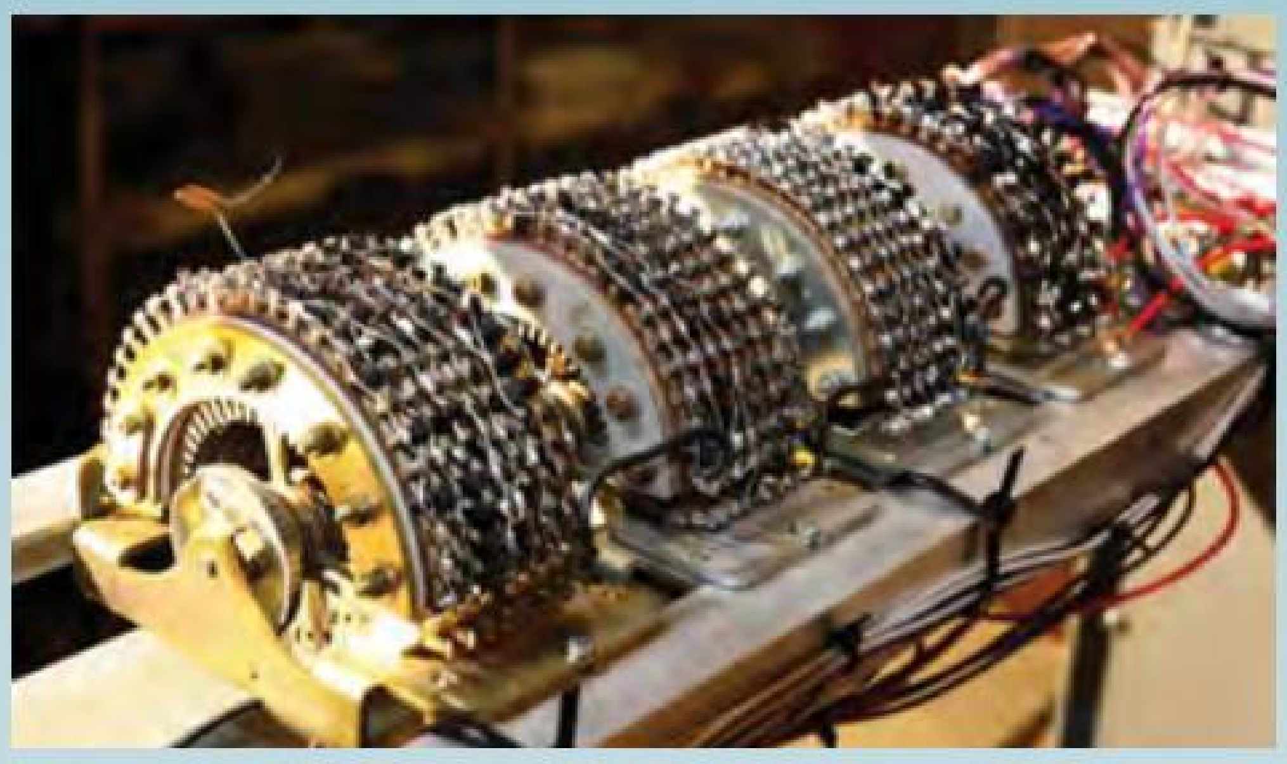
GPS with antenna

VPN1513 GPS smart module from Parallax

The VPN1513 GPS smart module with external antenna provides a complete GPS solution for electronics projects. This highly sensitive GPS receiver includes an external antenna, status LED, and a rechargeable battery back-up. An on-board voltage regulator makes the device ready to use with 3.3V and 5V microcontrollers.

The module features a simple command set for accessing NMEA 0183 GPS data. Example programs in PBASIC, Arduino, Propeller Spin, and Propeller C will help designers add the GPS module to microcontroller projects. More details at: **www.parallax.com/product/28510**

EDSAC display opens



The reconstructed EDSAC 'uniselector' design to hold initial orders, the equivalent of boot ROM in a modern PC

A key part of the reconstruction of one the most influential computers ever built – the ESDAC (Electronic Delay Storage Automatic Calculator) display – has been officially opened by Hermann Hauser, entrepreneur and EDSAC Project Chairman, at The National Museum of Computing.

EDSAC was originally built in the University of Cambridge immediately after World War II by a team led by Sir Maurice Wilkes. It was the first practical, general-purpose computer and marked the beginning of computer programming as a distinct profession. EDSAC was so successful that it was used in Nobel prize-winning scientific research and its design was later developed to create LEO, the world's first business computer.

At the official opening of the exhibit, several key elements of EDSAC were demonstrated. Bill Purvis showed how a program would be input before the advent of keyboards and how the result would be output before screens became commonplace. Peter Linnington revealed how, at the start of the computer age, delay lines were used as stores. As the climax, Chris Burton switched on the EDSAC clock, the beating heart of the machine.

The three-year project is on schedule for completion in late 2015.

Margaret Marrs, a programmer of the original EDSAC, and Joyce Wheeler, a research student who used the original EDSAC

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POWER
STEREO AUDIO DELAY
DSP Board 24bit/96kHz
Headphones

By NICHOLAS VINEN

Audio delay for PA systems

If you have ever been in a hall or concert venue which has multiple speakers, you will know that intelligibility can be a real problem. This is often caused by the different propagation times of the sounds from speakers near and far away from you. How do you fix it? By adding an audio delay. This unit does that by delaying the audio signal from the microphone by up to 640 milliseconds. But that's just the beginning of its capabilities. It is actually a fully-fledged stereo DSP board with a 32-bit processor running at 80MHz, and with appropriate software it is capable of providing other effects such as echo, reverb and compression.

PA systems in halls and larger venues can often present a problem with intelligibility, especially if you are sitting at the back. Picture the situation in a large church, for example. There will typically be a pair of large column speakers up the front of the congregation, but they cannot be turned up enough so that people at the back can hear the proceedings. So another pair of column speakers might be installed half way along or further back in the church.

That should mean that people at the back can now hear what's going on – but now the sound becomes jumbled because while the sound from the speakers close to you may be loud enough, it is actually being muddied by the delayed sound from the speakers up the front.

The solution is to delay the sound coming from the rear speakers and that is what this project does. In practice, if the distance between the front and rear

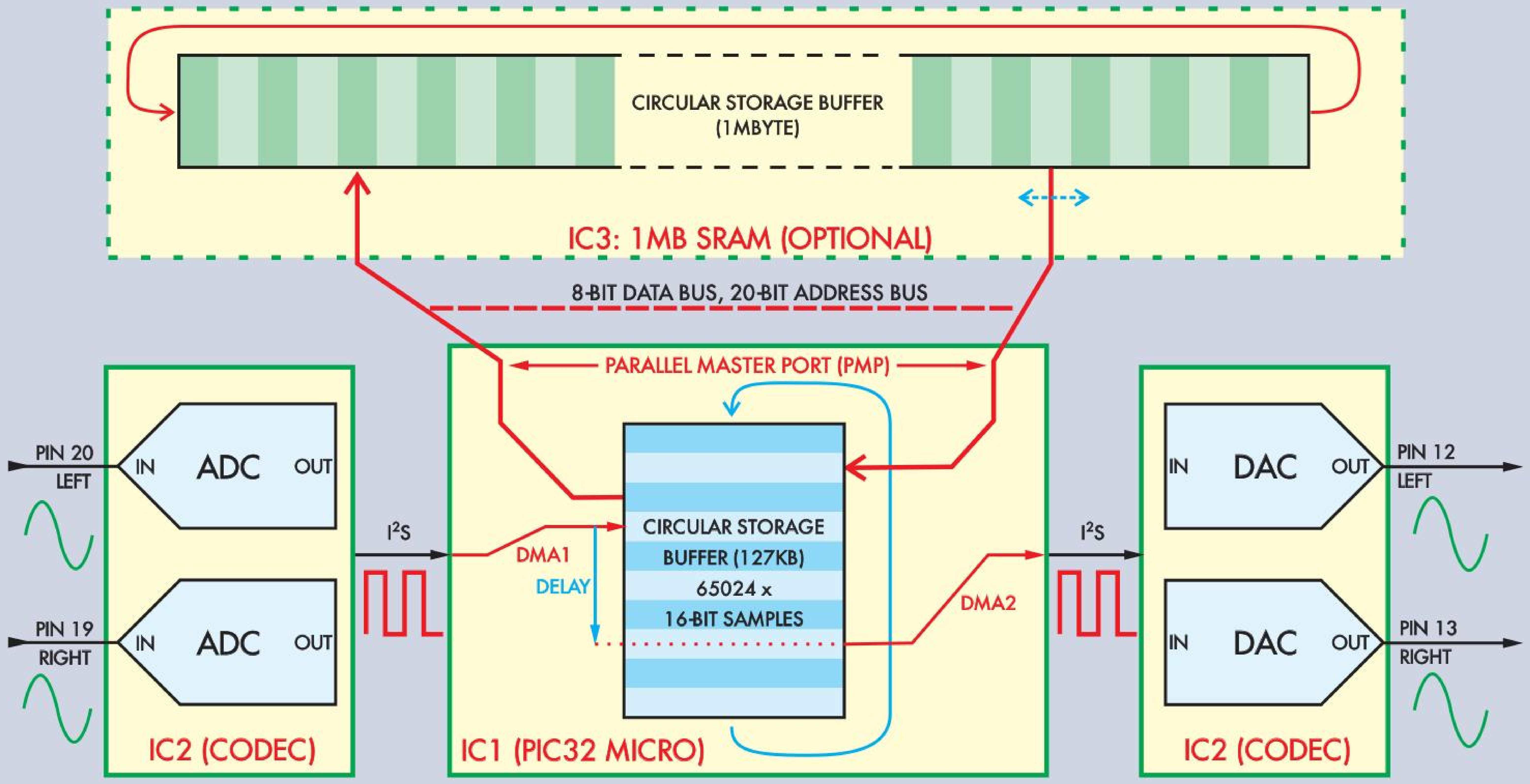


Fig.1: the basic concept. The incoming audio signal is fed into the analogue-to-digital converter (ADC) of CODEC IC2 and the resulting digital data is then fed into a circular recording buffer, which is 127KB of the static RAM on a PIC32 microcontroller (IC1). The delayed signal is then picked off from within this buffer and converted back to audio by IC2's digital-to-analogue converter (DAC) section. SRAM chip IC3 is added if you want a delay of more than 640ms.

speakers is more than about 10m or 15m, an audio delay can be very worthwhile.

Of course, this means that you need two separate PA systems: one for the rear speakers with the audio delay and one for the speakers at the front of the hall, church or whatever.

But what if you have a much larger hall? In that case, you might need to break the PA installation into three, with two sets of audio delays. Guess what? This project can also cater for that. In the simple mode, with just one delay required, it can operate in stereo. If two audio delays are required, it can operate with two separate channels, each with their own delay.

Now, some PA systems can have pretty good fidelity, so we wanted to produce the audio delay(s) while adding very little distortion and noise to the signal. We also wanted the delay unit to be cheap and easy to build.

The solution was to combine an all-in-one audio CODEC chip (digital COder/DECoder) with a PIC32 microcontroller that has a digital audio interface. These two chips, plus a few support components, give a 24-bit, 96kHz stereo analogue-to-digital converter (ADC), a similar digital-to-analogue converter (DAC) and enough processing power and memory for quite a long delay.

In fact, with its 128KB of internal RAM, the PIC32 we have chosen can provide a delay of up to 640 milliseconds. It also has a Parallel Master Port (PMP) which can interface directly with a standard static RAM (SRAM) chip. This allows us to have provision for up to 1MB of additional RAM to be used in case even longer delays are needed – up to six seconds, in fact. That could be useful in a very large venue such as a country show, with speakers spread along several hundred metres of a field.

We're using a sampling rate of 48kHz and a 16-bit voltage resolution, as this gives near-optimal performance with the CODEC chip we are using, while keeping memory storage requirements modest. The ADC performance is the limiting factor.

By the way, the author has published two previous audio delay units but this one has features lacking in those. Note that this is the first microcontroller-based audio delay we have published that does not require an external SRAM chip thanks to the large 128KB internal RAM in the PIC32.

Delay concept

The method of providing an audio delay is shown in Fig.1. The signal from the audio mixer is fed at line level into the analogue-to-digital converter (ADC) of the CODEC. The digital data is then fed into a circular recording buffer, which is 127KB of static RAM on the PIC32 microcontroller. We can then pick off the output signal from anywhere within this buffer.

Depending on the sampling rate (in this case, 48kHz), the difference between when the data is written and read out determines the time delay. Of course, the delayed data signal must then be converted back to audio by the digital-to-analogue converter (DAC) section of the CODEC.

So in essence, only two chips are required: microcontroller IC1 (the PIC32MX470F512H) and the stereo audio CODEC, IC2 (WM8731). An optional static RAM (SRAM) chip (IC3) is only fitted if you want a delay of more than 640 milliseconds (see Fig.3).

Circuit description

Fig.2 shows the circuit with IC1 and IC2. If you look at the project's PCB, you will notice that there is provision for many more components than are used in this circuit. One of those is IC3, which is shown in Fig.3. All the other 'missing' components will be featured in future projects which will employ the same core circuit.

Features and specifications

- Adjustable stereo delay of 0-640ms (6s if optional SRAM chip fitted)
- THD+N <0.03% (typically <0.02%), 20Hz-20kHz (20Hz-22kHz bandwidth; see Fig.6)
- Signal-to-noise ratio typically >76dB
- Optimal input signal range 0.5-2V RMS
- Output signal 1V RMS
- Input impedance 6kΩ (DC), 4kΩ (20kHz)
- 7.5-12V DC plugpack supply, current drain 60-80mA
- Delay adjustment via internal trimpot or external control knob
- Uses the latest PIC32 microcontroller
- Future expansion: add extra modes such as echo, reverb or compression

So, referring to the top left-hand corner of the circuit, the unbalanced stereo audio signal is applied to 6.35mm jack socket CON1. If a mono plug is used, the signal will be applied to the right channel input, while the left channel input will be shorted to ground.

The left and right channel signals first pass through RC filters comprising 1kΩ resistors and 1nF capacitors, to remove ultrasonic and RF components which would interfere with the ADC's operation. The signals then go into adjustable attenuators, which consist of two 5kΩ trimpots, VR5 and VR6. While these can be individually adjusted, normally they would be set to give the same signal level for both channels.

These attenuators are required because IC2 runs off 3.3V and thus it can only handle a signal of up to about 1V RMS (2.828V peak-to-peak) before clipping. For input signals below 1V RMS, VR5 and VR6 are set at maximum. The attenuated signals are AC-coupled to IC2's inputs by 1µF non-polarised capacitors. In order for the signal handling to be maximised and for symmetrical clipping in the event of overload, the input signals are biased to half the supply voltage of 3.3V, ie 1.65V.

This half-supply DC bias comes from IC2 and is fed to the line inputs at pins 19 and 20. This voltage also appears at pin 16 (VMID) where it is filtered by a pair of external capacitors for noise and ripple rejection.

IC2 uses crystal X1 (12MHz) to generate an internal clock, which is then divided down to produce the sampling rate for both its ADC and DAC. These dividers are configurable and are controlled by microcontroller IC1.

Normally, a 12.288MHz crystal or similar would be required to get a sampling rate of 48kHz (by dividing by 256) but IC2 has a special 'USB mode' designed to operate with a 12MHz clock, as used for USB communications. So we use a 12MHz crystal, which is easier to obtain.

IC2 continuously samples the two analogue input signals at pins 20 and 19 and converts the voltage levels at these pins to one of 65,536 possible values (2^{16}) at 20.8µs intervals. These values are serially streamed out in digital format from pin 6. Pins 2, 3 and 5 provide the clock signals required to interpret this data. Respectively, these are the master clock (MCLK, 12MHz), bit clock (BCLK, 3.072MHz = 48kHz × 2 × 32 bits) and left/right sample clock (LRCK, 48kHz).

The master clock is normally used to synchronise multiple digital audio devices in a system. In this case, we're simply using it as a reference clock for IC1, as it has a more precise frequency than IC1's internal oscillator.

The bit clock (BCLK) is at 64 times the sampling rate because the audio data is padded to 32 bits per channel. We're only using 16 bits per channel, so half the time this output will be zero (low) but the CODEC can be configured for 24-bit operation too, hence the higher clock rate. This clock is used by the micro to determine when a new data bit appears at the ADCDAT output.

The left/right sample clock indicates the start of a new value being transmitted on ADCDAT, as well as allowing the micro to determine which channel this value is for (low = right, high = left). Since this changes twice for each sample, the frequency of this signal equals that of the sampling rate, ie, 48kHz.

After receiving this data and delaying it for the appropriate amount of time, IC1 sends it back verbatim to IC2's pin 4, the DAC input data pin. The same clocks (ie, BCLK and LRCK) are used to time this data and thus the DAC and ADC sampling rates are locked together.

IC2's internal DAC then converts the received data to voltages on pins 12 and 13 (LOUT and ROUT respectively). These signals are AC-coupled using 1µF capacitors and DC-biased to ground using 47kΩ resistors. The 100Ω series resistors isolate any cable or load capacitance from IC2's internal op amp buffers.

From there, the signals pass to the output at 6.35mm jack socket CON2. As explained, IC2 runs off 3.3V, so the maximum output signal level is limited to around 1V RMS (2.828V peak-to-peak). This is sufficient to drive virtually any amplifier or mixer.

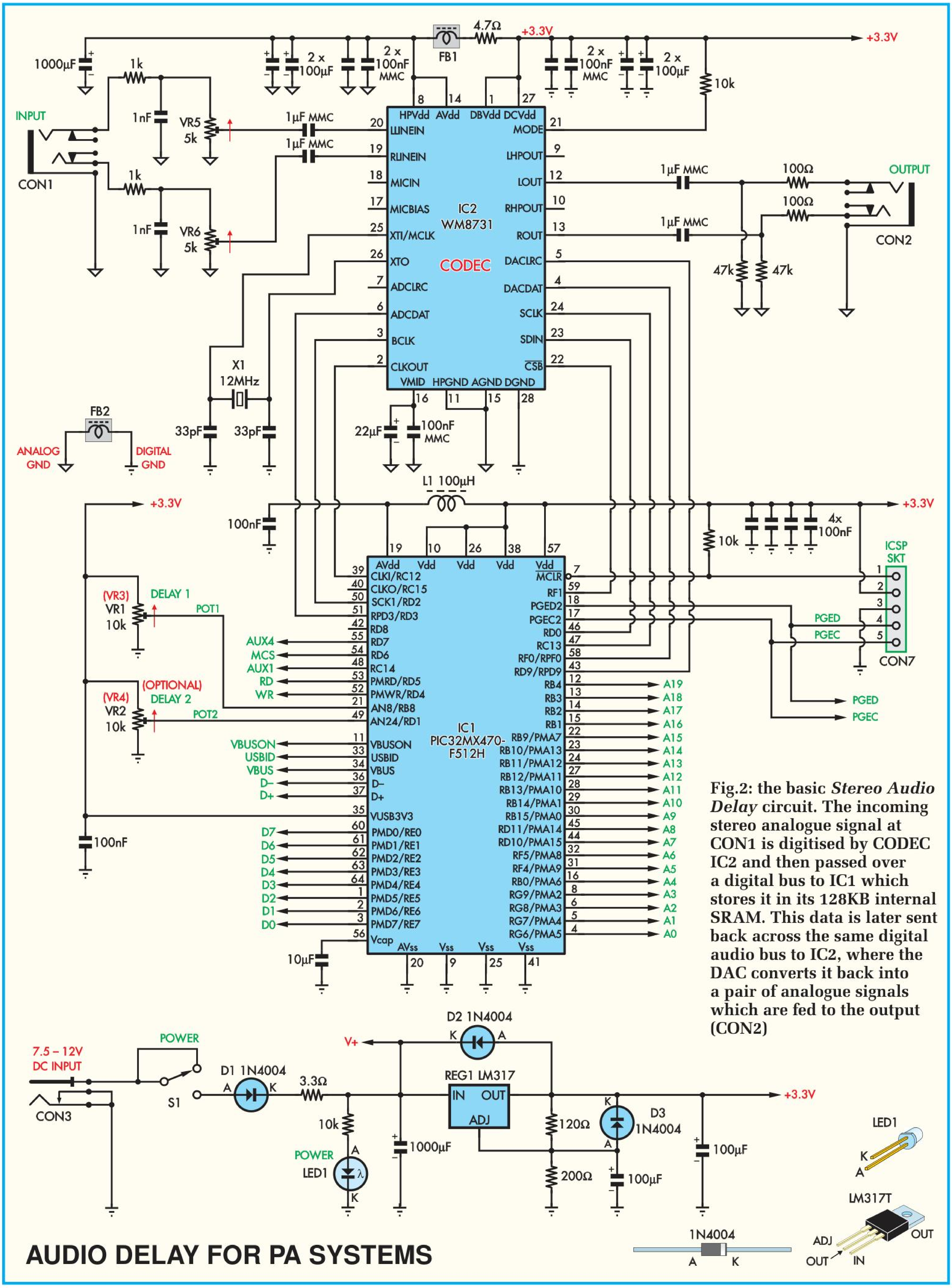
Note that the WM8731 codec has a 'pass-through' mode whereby a direct analogue connection is made from pin 20 (LLINEIN) to the analogue buffer feeding pin 12 (LOUT) and similarly, from pin 19 (RLINEIN) to pin 13 (ROUT). We take advantage of this if the delay pot is set at minimum; in this case, there is essentially no delay and the distortion and noise from the unit drop too.

Microcontroller

As noted above, we chose the PIC32MX470F512H for a number of reasons. It is one of the latest PIC32 chips and as such it has two enhanced SPI peripherals which directly support all the common digital audio formats, including I^{2}S, left-justified, right-justified and DSP modes. The WM8731 CODEC supports all these modes and we are using left-justified mode because this allows us to set up the SPI peripheral to ignore the 16 trailing zeros for each sample.

This PIC32 chip also has four very flexible DMA (direct memory access) units. These are used to copy data between other peripherals and/or RAM simultaneously while the processor is busy doing something else.

In fact, they are so flexible that for a simple stereo delay, we just need


+3.3V
4.7Ω
FB1
1000µF
1k
2 x 100µF
2 x 100nF MMC
2 x 100nF MMC
2 x 100µF
10k
INPUT
1nF
VR5 5k
1µF MMC
1µF MMC
CON1
VR6 5k
IC2
WM8731
CODEC
HPVdd AVdd DBVdd DCVdd
LLINEIN
RLINEIN
MICIN
MICBIAS
XTI/MCLK
XTO
ADCLRC
ADCDAT
BCLK
CLKOUT
VMID HPGND AGND DGND
MODE
LHPOUT
LOUT
RHPOUT
ROUT
DACLRC
DACDAT
SCLK
SDIN
CSB
100Ω
100Ω
OUTPUT
CON2
47k
47k
X1 12MHz
33pF
33pF
FB2
ANALOG GND
DIGITAL GND
22µF
100nF MMC
L1 100µH
100nF
4x 100nF
10k
ICSP SKT
CON7
PGED
PGEC
(VR3) VR1 10k DELAY 1 POT1
(OPTIONAL) (VR4) VR2 10k DELAY 2 POT2
AUX4
MCS
AUX1
RD
WR
VBUSON
USBID
VBUS
D–
D+
D7
D6
D5
D4
D3
D2
D1
D0
100nF
10µF
IC1
PIC32MX470-F512H
AVdd Vdd Vdd Vdd Vdd
CLKI/RC12
CLKO/RC15
SCK1/RD2
RPD3/RD3
RD8
RD7
RD6
RC14
PMRD/RD5
PMWR/RD4
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A6
A5
A4
A3
A2
A1
A0
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POWER
S1
D1 1N4004
3.3Ω
10k
POWER LED1
1000µF
V+
D2 1N4004
REG1 LM317
IN OUT ADJ
120Ω
200Ω
100µF
D3 1N4004
100µF
+3.3V
LED1
K
A
LM317T
ADJ OUT IN OUT
1N4004
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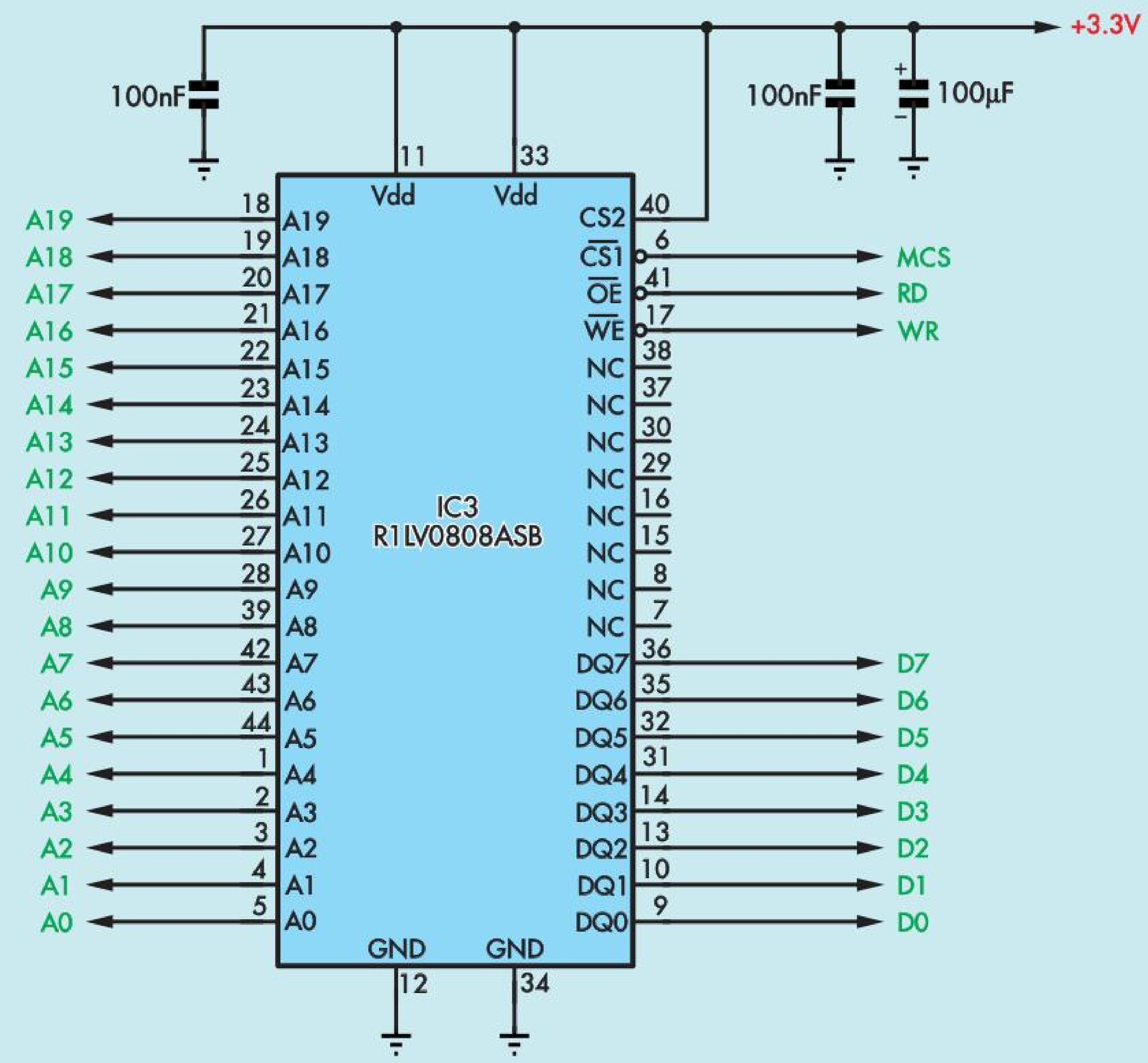
AUDIO DELAY FOR PA SYSTEMS

Fig.2: the basic *Stereo Audio Delay* circuit. The incoming stereo analogue signal at CON1 is digitised by CODEC IC2 and then passed over a digital bus to IC1 which stores it in its 128KB internal SRAM. This data is later sent back across the same digital audio bus to IC2, where the DAC converts it back into a pair of analogue signals which are fed to the output (CON2)



OPTIONAL MEMORY EXPANSION

Fig.3: adding a Renesas R1LV0808ASB 1MByte SRAM chip allows the delay to be increased from a maximum of 640ms up to a maximum of six seconds. It runs from the same 3.3V supply as IC1 and is driven by the Parallel Master Port (PMP) memory interface in the PIC32.

to set up two DMA channels, one to read data from the CODEC and place it into a RAM buffer and another to read from a different location in that RAM buffer and send it back to the CODEC. The CPU can then go into idle mode while the DMA and SPI units do all the actual work! The processor core only needs to wake up periodically to check if the delay has been changed via the adjustment pot (using an interrupt request [IRQ]) and if necessary, adjust the DMA memory pointers to suit.

The main delay adjustment pot is wired to analogue input pin 21 of IC1 (AN8). Normally, this is a multi-turn trimpot so that the delay can be preset, but in some cases, it may be desirable to have an externally accessible knob and so 9mm pot VR3 can be fitted instead.

Provision has also been made for a second delay adjustment pot (VR2 or VR4). This allows the unit to provide two separate delays of the same mono signal; the delays can be set independently. This could be useful for a PA system where the speakers are placed far apart.

IC1 can detect whether VR2 or VR4 is installed since it has weak pull-up and pull-down current sources/sinks on every I/O pin which can be individually enabled or disabled (+250/–50µA). IC1 turns on the pull-up and pull-down currents alternately and measures the change in voltage on that pin.

Without VR2/VR4, the voltage difference will be nearly the supply voltage, ie, 3.3V. If either pot is installed, the change will be much less and so the unit knows to operate in dual mono delay mode.

The MCLK signal from IC2 goes to pin 39 of IC1, which is the clock input (OSCI), while the digital audio data (BCLK, DACDAT, DACLRC and ADCDAT) connects to pins which are routed to IC1's internal SPI/digital audio peripheral #1. This requires the bit clock to be connected to pin 50, but the other signals can go to one of several pins and are routed via its 'Peripheral Pin Select' digital multiplexer.

The rest of the components surrounding the microcontroller are various power supply bypass capacitors, including a 10µF capacitor at pin 56 (VCAP) which is required to filter the 2.5V core supply. This is derived from the 3.3V rail by a low-dropout regulator within IC1. There is also provision for CON7, which is a 5-pin in-circuit programming header (ICSP), with a 10kΩ pull-up resistor for $\overline{\text{MCLR}}$ (pin 7) to prevent spurious resets.

IC1 has a separate analogue supply pin (pin 19, AVdd) for its ADC and a 100µH axial inductor is used to filter this supply. This ADC is used to sense the positions of VR1-VR4 by measuring the voltage at their wiper(s).

At the time of writing, the PIC32MX470 is so new that it is only available as engineering samples, but production chips should be available by the time you read this. As usual, pre-programmed chips will be available from the *EPE Online Shop*.

Optional memory expansion

Virtually all of IC1's 128KB internal RAM is dedicated for use as a delay buffer and should be sufficient for most applications. But if a longer delay is required, IC3 can be fitted as mentioned above (see Fig.3). This is a Renesas R1LV0808ASB 1MB SRAM chip. It runs from the same 3.3V supply as IC1 and its memory is arranged as 8 bits × 1048576 (2^{20}). This is driven by the Parallel Master Port (PMP) memory interface in the PIC32.

The PMP on this PIC32 has 16 address lines (PMA0-15), eight data lines (PMD0-7) and read/write strobe pins PMRD/PMWR. These are connected to IC3's A0-15 address lines (in no particular order), DQ0-7 bidirectional data lines, $\overline{\text{OE}}$ (output enable) and $\overline{\text{WE}}$ (write enable) respectively. The PMP can be driven by one or more DMA channels to allow copying between internal and external RAM while the processor is otherwise occupied.

Since a 1MB 8-bit SRAM requires 20 address lines and IC1 only has 16, the other four are driven by GPIO (general-purpose input/output) pins 12-15 (RB1-RB4). Thus, the Parallel Master Port can read or write blocks of 64KB of memory (2^{16}), with the four GPIO pins selecting one of 16 different 64KB blocks to access at any given time.

Besides the power supply pins (which are bypassed with one electrolytic and two ceramic capacitors), the only remaining pins on IC3 are two chip select lines, $\overline{\text{CS1}}$ and CS2. With CS2 permanently tied to +3.3V, $\overline{\text{CS1}}$ controls whether IC3's interface is active and this is driven by GPIO pin 54 (RD6) of IC1 (active-low).

IC1 can detect whether IC3 is present simply by attempting to use it. With weak internal pull-downs enabled on

Parts List

1 double-sided PCB, coded 01110131, 148 × 80mm available from the *EPE PCB Service*
1 ABS plastic instrument case, 155 × 86 × 30mm
1 set front and rear panel labels
4 No.4 × 6mm self-tapping screws
1 12MHz HC-49 crystal (X1)
1 100μH axial RF inductor (L1)
1 10kΩ multi-turn vertical trimpot (VR1) OR 1 × 10kΩ 9mm horizontal potentiometer (VR3)
2 5kΩ horizontal mini trimpots (VR5,VR6)
2 6.35mm PCB-mount stereo switched jack sockets (CON1,CON2)
1 5-way pin header, 2.54mm pitch (CON7)
1 PCB-mount SPDT right-angle toggle switch
1 PCB-mount switched DC socket to suit plugpack
1 7.5-12V 100mA DC plugpack supply
2 4mm ferrite suppression beads
1 M3 × 6mm machine screw and nut

Semiconductors
1 PIC32MX470F512H-I/PT 32-bit microcontroller programmed with 0111013A.hex (IC1) (available from www.siliconchip.com.au)
1 WM8731SEDS 24-bit 96kHz stereo CODEC (IC2) (element14 1776264)
1 LM317T adjustable regulator (REG1)
1 3mm blue LED (LED1)
3 1N4004 diodes (D1-D3)

Capacitors
2 1000μF 25V electrolytic
6 100μF 16V electrolytic
1 22μF 16V electrolytic
1 10μF 6.3V 0805 SMD ceramic
4 1μF 50V monolithic ceramic
11 100nF 6.3V 0805 SMD ceramic
2 1nF MKT
2 33pF ceramic disc

Resistors (0.25W, 1%)
2 47kΩ
3 10kΩ
2 1kΩ
1 200Ω
1 120Ω
2 100Ω
1 4.7Ω 0.5W 5%
1 3.3Ω 0.5W 5%

Extra parts for longer delay
1 R1LV0808ASB-5SI 8MBit 3.3V SRAM (IC3) (element14 2068153)
1 100μF 16V electrolytic capacitor
2 100nF 6.3V 0805 SMD ceramic capacitors

Extra parts for dual mono delay
1 10kΩ multi-turn vertical trimpot (VR2) OR 1 × 10kΩ 9mm horizontal potentiometer (VR4)

the data bus, it will simply read zeros if IC3 is absent, so we just need to do a test write to verify that it is connected and operating normally. If so, the delay adjustment range is set as 0-6s rather than 0-645ms.

Note that when using a RAM chip such as this, the order in which the data and address lines are connected doesn't matter. All that really matters is that when you write data to a particular address and then read that same address later (ie, all the address lines are in the same state), you get the same data back. Any jumbling of the address or data lines in a write operation is automatically reversed during a read.

This is in contrast to DRAM (dynamic RAM), where the memory is broken up into rows and columns, and it's much faster to access data sequentially than at random. SRAM is more akin to a large register file and in general, performance is identical regardless of the address pattern used during read or write operations.

Power supply

Toggle switch S1 switches power, while diode D1 provides reverse polarity protection. A 3.3Ω resistor limits the inrush current and REG1 provides a regulated output of 3.15-3.55V (nominally 3.35V), programmed with the 120Ω and 200Ω resistors. Diodes D2 and D3 protect REG1 against its input being suddenly shorted (however unlikely that is), while the capacitor at D3's anode improves high-frequency supply ripple rejection.

Blue LED1 is the power indicator and its current-limiting resistor is used to run it at 0.4-0.8mA, depending on the incoming supply voltage.

As well as the aforementioned supply bypass capacitors for microcontroller IC1 and optional SRAM IC3, there are also a number of bypass capacitors for IC2. Each of its various supply pins has a 100nF ceramic and 100μF electrolytic capacitor to ground. There is also a low-pass filter for its analogue supply pins, to reduce the amount of supply noise that might be coupled from the digital circuitry. This is necessary to get good analogue performance, especially for the ADC.

This filter consists of a 4.7Ω resistor with a ferrite bead over one of its leads, in series between the digital and analogue +3.3V supplies, with a 1000μF filter capacitor for the analogue supply. There is also a ferrite bead on the wire connecting the analogue and digital grounds together.

Software

While the software to implement the delay function is not overly complex, there is still quite a bit going on. As usual, the source code will be available for download from the *EPE* website.

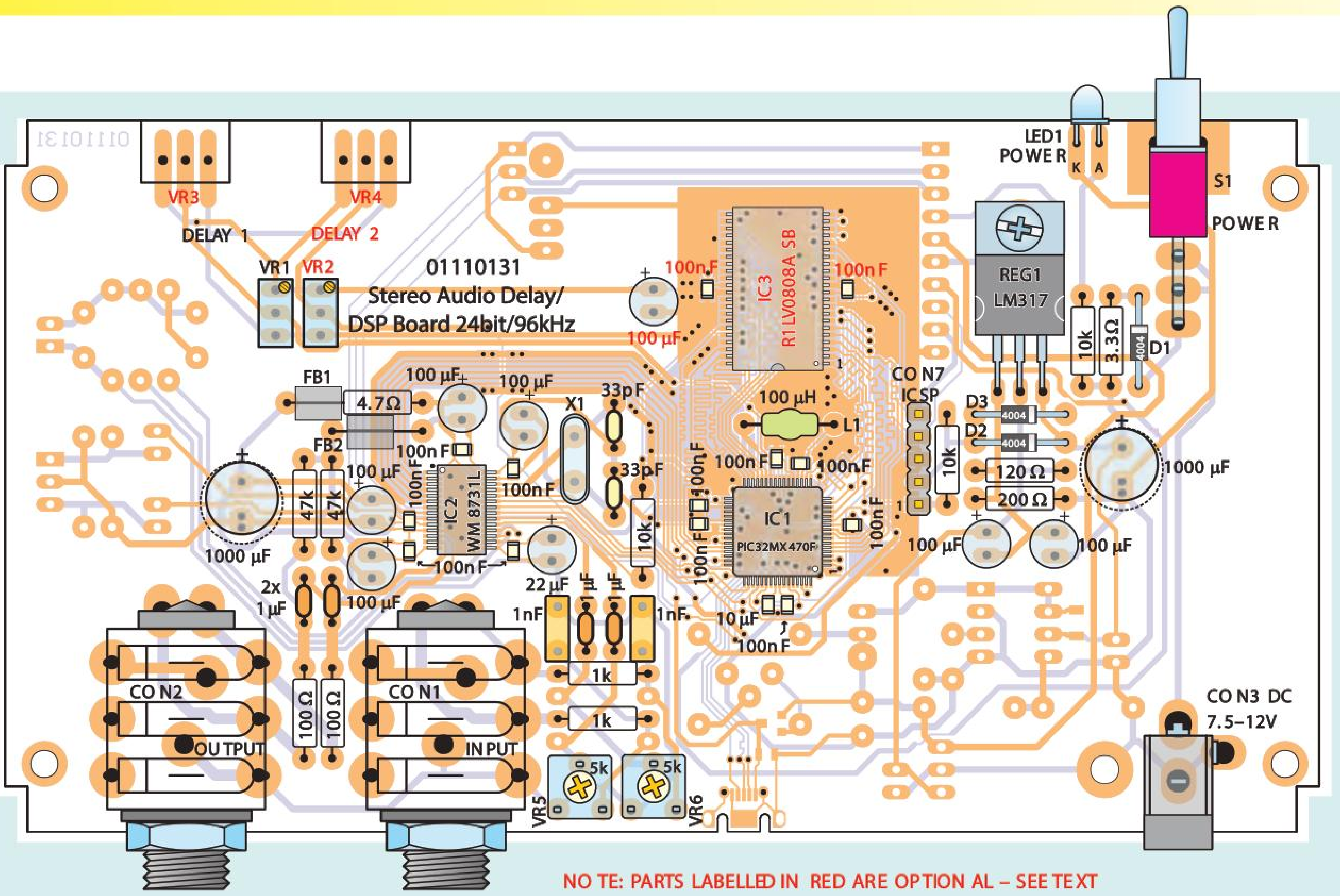
Most of the complexity resides in the 'drivers' which must stream digital data between the microcontroller and CODEC and between the microcontroller's internal RAM and the external SRAM chip. Circular buffering is used to allow for continuous recording and playback.

Construction

All the parts mount on a double-sided PCB available from the *EPE PCB Service*, coded 01110131 and measuring 148 × 80mm. This fits into a snap-together ABS plastic instrument case measuring 155 × 86 × 30mm.

Fig.4 shows the parts layout on the PCB. Don't worry about the unpopulated pads; as stated above, they are there to accept extra circuitry to be described in the future.

Start the assembly by fitting the SMD ICs. IC1 and IC2 are required, but remember that IC3 (the SRAM chip) is optional. They are each fitted in more or less the same manner, as described below. Note that IC1 and IC2 have


01110131
VR3
VR4
DELAY 1
DELAY 2
VR1
VR2
01110131
Stereo Audio Delay/
DSP Board 24bit/96kHz
LED1
POWER
K A
S1
POWER
REG1
LM317
10k
3.3Ω
4004
D1
D3
D2
4004
120Ω
200Ω
1000 µF
100 µF
100 µF
IC3
R1LV0808A SB
100nF
100nF
100 µF
FB1
4.7Ω
FB2
100 µF
100 µF
X1
33pF
33pF
100 µH
L1
CON7
ICSP
10k
100nF
100nF
IC2
WM 8731L
100nF
100nF
100nF
IC1
PIC32MX470F
100nF
100nF
100nF
1000 µF
47k
47k
100 µF
100 µF
2x
1 µF
22 µF
1nF
1nF
10 µF
100nF
10k
1 µF
1 µF
1k
1k
CON2
OUTPUT
100Ω
100Ω
CON1
INPUT
5k
5k
VR5
VR6
CON3 DC
7.5–12V
NOTE: PARTS LABELLED IN RED ARE OPTIONAL – SEE TEXT

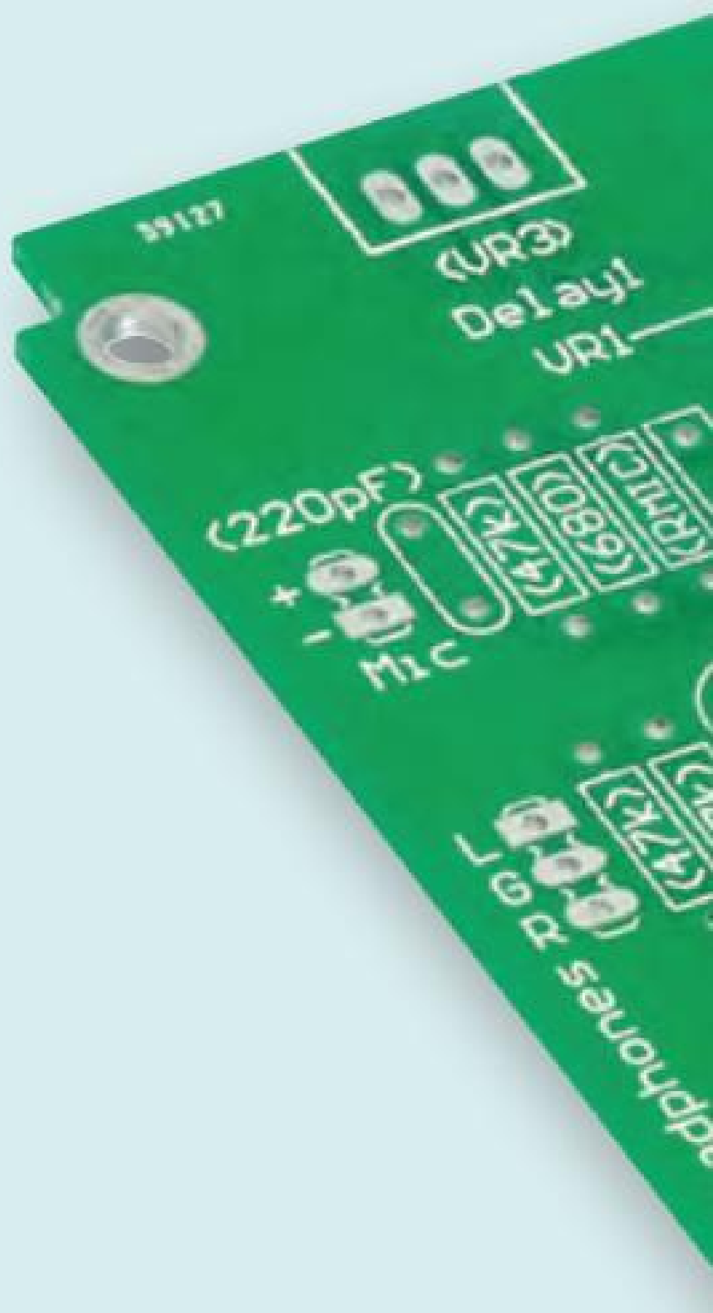


Fig.4: follow this parts layout diagram to build the PCB, starting with the SMD ICs and the SMD capacitors. The parts labelled in red are optional. Install SRAM chip IC3 only if you need a delay that's longer than 640ms and install VR2 (or VR4) if you want a dual-channel delay unit with independently adjustable delays.

very closely spaced pins (about 0.5mm apart) but if you are careful, it's possible to hand solder these parts reliably.

Begin by placing the IC to be installed alongside its pads and identify pin 1. In each case, there should be a small dot or depression in one corner (you may need to view the part under a magnifying lens and a strong light to spot it). This must line up with the dot and pin 1 marking on the overlay diagram and this should also be shown on the PCB silkscreen printing.

Check that the part is the right way around, then apply a very small amount of solder to one of the corner pads. If you are right-handed, it's easiest to start with the top pad on the righthand side. If you are left-handed, start with the top pad on the left side. Avoid getting any solder on the adjacent pad.

That done, pick up the IC with a fine-tipped pair of angled tweezers and while heating the solder pad, gently slide it into place. Don't take too long doing this; if you heat the pad too much it could lift, so after a few seconds, if it isn't in place, lift off and wait for the PCB to cool down before trying again. Once you have placed it, check the part's alignment under a magnification lamp or similar. All the pins must be accurately centred over their respective pads.

If they aren't, don't panic; it's just a matter of re-melting the solder on that one joint and carefully nudging the IC in the right direction. You might get it right first time or it may take several attempts to get it in place, the goal being to eventually get it properly aligned without spreading solder onto any other pins or pads and without heating the PCB or IC enough to damage them.

If you do get some solder on the adjacent pin, it's still possible to adjust the position but you will now need to heat both pins to get it to move. Take care though, because if three or more pins end up with solder on them, you will likely need to remove the part, clean up the pads using solder wick and then start again.

Once the part is in place, solder the diagonally opposite pin, then re-check the alignment under magnification as it may have moved slightly. If it has, you can reheat this second pad and gently twist the IC back into alignment. Once you're happy, solder the rest of the pins – and don't worry too much about bridging them with solder, it's almost impossible to avoid. Remember to refresh that first pin you soldered.

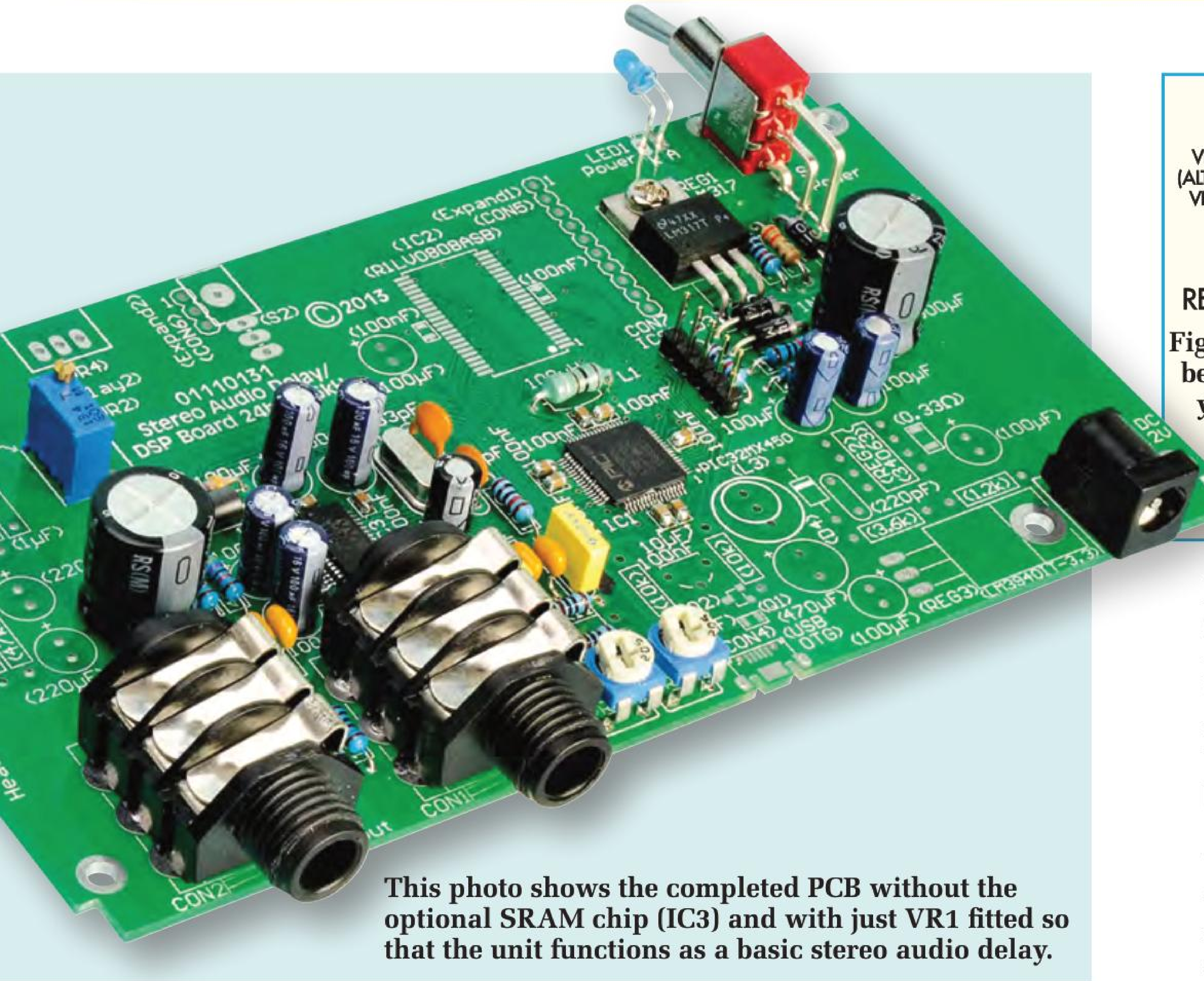
Once all the pins have been soldered, spread a thin layer of flux paste along all the pins and gently press down on them with solder wick to suck up the excess solder. If done correctly, this will leave you with neatly soldered pins and no solder bridges. Go over all the pins once with the solder wick, then check under a magnifier for any remaining bridges. If there are any, add a dab of flux paste, then go back over them with the solder wick.

Once that IC is in place, you can repeat the above procedure until all the SMD ICs have been fitted.

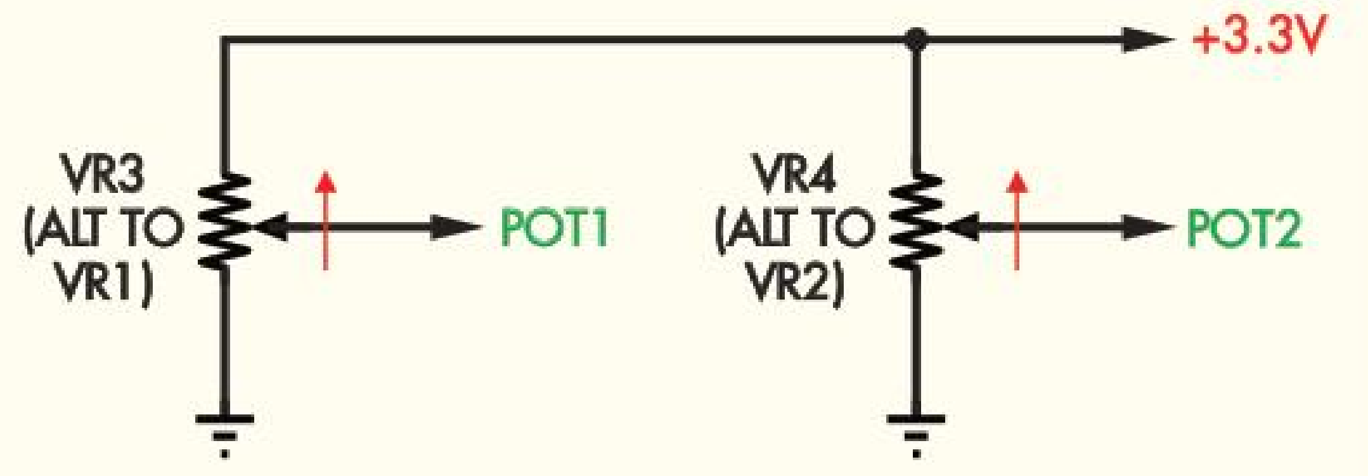
By the way, rather than hand-solder these parts, you could use a home reflow oven (as described in *EPE* in April 2014 – *Beta-Layout's Re-flow Oven Kit and Controller*). However, we realise that most constructors won't have such a set-up and hand soldering is quite straightforward provided you follow the above procedure and have a good magnifying lamp and a fine-tipped soldering iron.

Once all the ICs are in place, follow with the SMD ceramic capacitors, using a similar procedure; ie, add solder to one pad, then heat this solder and slide the part into place before soldering the other pad and refreshing the initial joint. Be careful not to get the SMD capacitors mixed up.

In each case, wait about 10 seconds after soldering the first side of the capacitor before applying solder to the other side. This is necessary because the solder joint can remain molten for quite some time. If you try to solder the



This photo shows the completed PCB without the optional SRAM chip (IC3) and with just VR1 fitted so that the unit functions as a basic stereo audio delay.



REPLACING VR1 & VR2 WITH VR3, VR4

Fig.5: potentiometers VR3 and VR4 can be installed instead of VR1 and VR2 if you want the delays to be externally adjustable (refer to the text for the various options). Don't install both VR1 and VR3 or both VR2 and VR4.

Capacitor Codes

Value	µF Value	IEC Code	EIA Code
1µF	1.0µF	1u	105
1nF	0.001µF	1n	102
33pF	NA	33p	33

opposite pad too early, the capacitor will move out of alignment and it's frustrating trying to re-align capacitors when this happens.

Take care also not to short any IC pins when soldering the SMD capacitors. They are located close to the ICs for performance reasons.

Through-hole parts

Proceed now with the low-profile components such as the resistors and diodes. Be sure to slip a ferrite bead (FB1) over one of the 4.7Ω resistor's leads before soldering it in place. It's best to check each resistor value with a DMM before fitting it as the colour bands can be difficult to read. The diodes are all the same type and all have their cathode bands facing to the top or righthand edge of the board.

In the case of FB2, slip the bead over a resistor lead off-cut and then solder it to the board as shown in Fig.4. You can also mount axial inductor L1 at this time. Follow with REG1; bend its leads down about 6mm from its body, feed them through the PCB holes, fasten its tab to the PCB using an M3 × 6mm machine screw and nut and then solder and trim the leads.

The horizontal trimpots can go in next, followed by the MKT and ceramic capacitors (disc and monolithic multilayer) and then pin header CON7 (not required if you have a pre-programmed microcontroller). That done, solder DC socket CON3 in place, followed by either VR1 or VR3 (to externally adjust the delay) but not both.

In addition, you can optionally fit VR2 or VR4 (but not both). As mentioned earlier, if either VR2 or VR4 is fitted, the unit will operate as two separate mono delay channels.

Now fit crystal X1 and the electrolytic capacitors, taking care to ensure that the latter are correctly oriented. Follow with power switch S1 and the blue power LED (LED1). This LED should have its leads bent at right angles 4mm from the base of the lens and then soldered so that the centre of the lens (and thus this short lead section) is 6.5mm above the top surface of the PCB.

This aligns the centre of the LED with the centre of the switch. When bending the LED's leads, pay attention to the 'A' and 'K' markings on the PCB as the longer (anode) lead must be soldered to the anode pad. You can accurately set the height of the LED by cutting a 6.5mm wide cardboard spacer and pushing the leads down onto this.

The assembly can now be completed by soldering jack sockets CON1 and CON2 in place. Note that if you are

Resistor Colour Codes

☐	No.	Value	4-Band Code (1%)	5-Band Code (1%)
☐	2	47kΩ	yellow violet orange brown	yellow violet black red brown
☐	3	10kΩ	brown black orange brown	brown black black red brown
☐	2	1kΩ	brown black red brown	brown black black brown brown
☐	1	200Ω	red black brown brown	red black black black brown
☐	1	120Ω	brown red brown brown	brown red black black brown
☐	2	100Ω	brown black brown brown	brown black black black brown
☐	1	4.7Ω	yellow violet gold brown	yellow violet black silver brown
☐	1	3.3Ω	orange orange gold brown	orange orange black silver brown

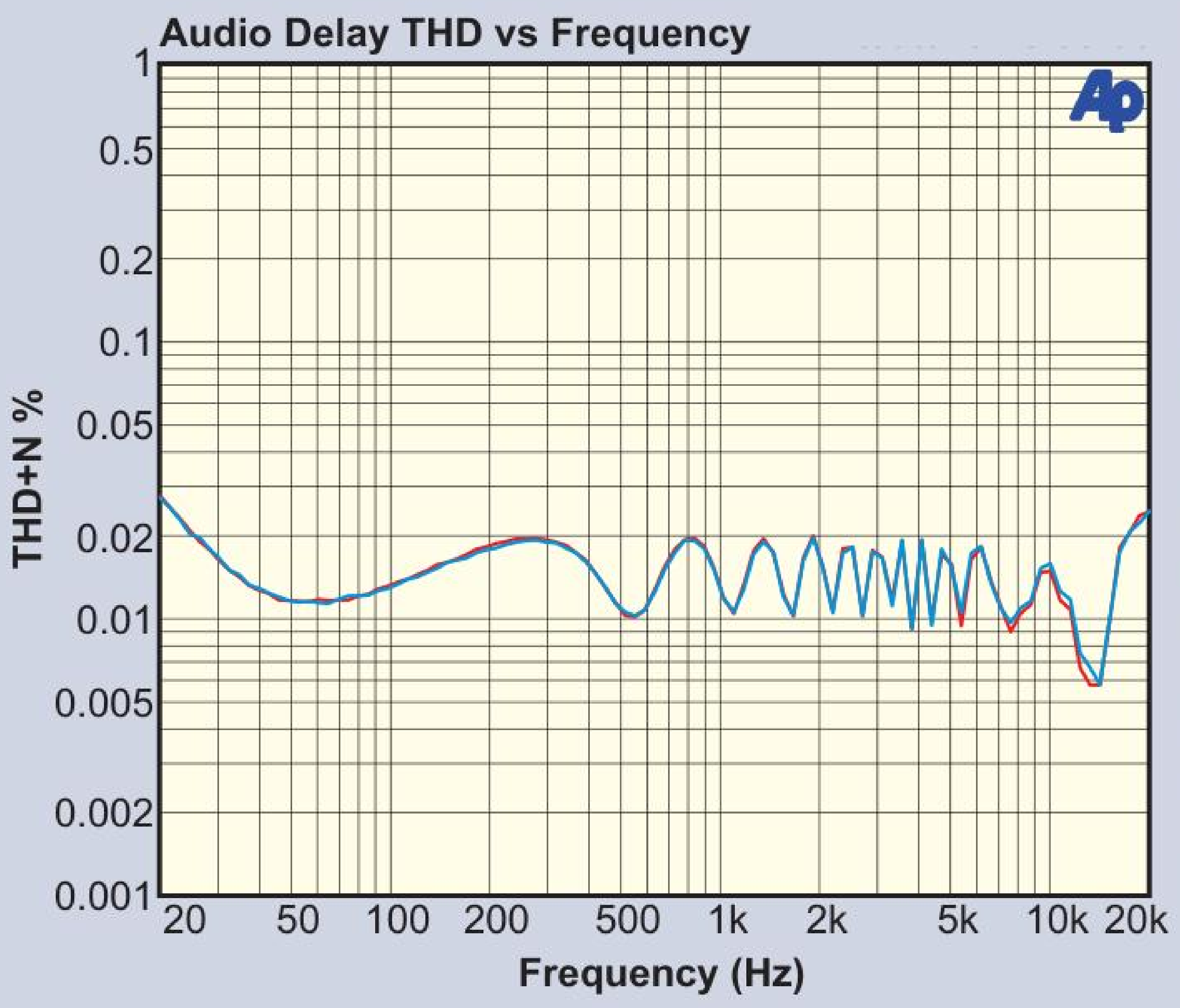


Fig.6: this graph shows that the delay unit should have little impact on sound quality, even when used with a high-quality PA system (input signal level is 1V RMS). The 'oscillation' between 0.01% and 0.02% is due to the beat products of the 48kHz sampling rate and the input signal frequency (this is a form of aliasing).

using the type with six pins, you will also have to file or cut down the tall, rounded pieces of plastic just behind the screw threads (see photos), to prevent them from later fouling the case.

Checking it out

If you purchased a blank PIC32 chip, program it now (or purchase a programmed chip from the *EPE Online Shop*).

The circuit can be powered from a PICkit3 programmer at 3.3V. In fact, the whole unit will operate normally from this supply, so you can test the audio signal path immediately after programming the chip.

If you don't have a PICkit3, you will need to power the unit from a 7.5-12V DC plugpack. In this case, connect a voltmeter across the 3.3Ω resistor next to D1. Small alligator clip leads (or other test probe clips) are very useful for this purpose, as you can switch the unit on while watching the meter reading and switch it off immediately should the voltage across this resistor rise too high.

Expect a reading in the range of 0.2-0.3V, depending on the exact resistor value and how you have configured the unit. Much less than 0.2V indicates that there is an open circuit somewhere, while much more than 0.3V indicates a likely short circuit. If the reading is outside the expected range, switch off immediately and check for faults.

The most likely faults would be one or more pins on an SMD chip bridged to an adjacent pin or not properly soldered to the PCB pad. Other possible faults include incorrect device orientation (primarily ICs, diodes and electrolytic capacitors) or poor/bridged through-hole solder joints.

Assuming all is OK, feed a line level audio signal into the input and connect the output to an amplifier. You should hear clear, undistorted audio with no delay. You can then adjust the delay pot setting(s) and check that this operates as expected. A fully clockwise setting will give a delay of either 640ms (no SRAM fitted) or 6s (SRAM fitted).

If you know what signal level will be applied to the input when the unit is in use, you can adjust trimpots VR5 and VR6 to suit now. To do this, feed in a sinewave of the expected amplitude, then adjust these pots so that the outputs measure just under 1VAC. Any higher will lead to clipping and distortion. Ideally, you should calibrate them separately.

If you aren't sure of the input signal amplitude, you can wait until you get the unit 'in the field' to set the level pots. One method is to turn them clockwise until clipping and distortion start, then back them off slightly. However, this does risk setting the level high enough for slight clipping to occur which may not always be obvious. If the input signal is under 1V RMS (0dBu = 0.775V RMS), then you can simply set them both fully clockwise.

If all else fails, simply set VR5 and VR6 half-way. The unit can then handle input signals up to about 2V RMS, but if the signal level is significantly lower than this, the noise and distortion will be less than optimal.

Case preparation

The front panel of the case needs holes for the power switch and LED, while the rear panel requires holes for the two jack sockets and the DC power plug. The front and rear panel artworks (Fig.7) can be used as drilling templates. These can also be downloaded from the *EPE* website in a single PDF file.

It's simply a matter of printing (or copying) the labels, then accurately taping them to the panels, drilling a pilot hole in the centre of each location indicated and then enlarging each to

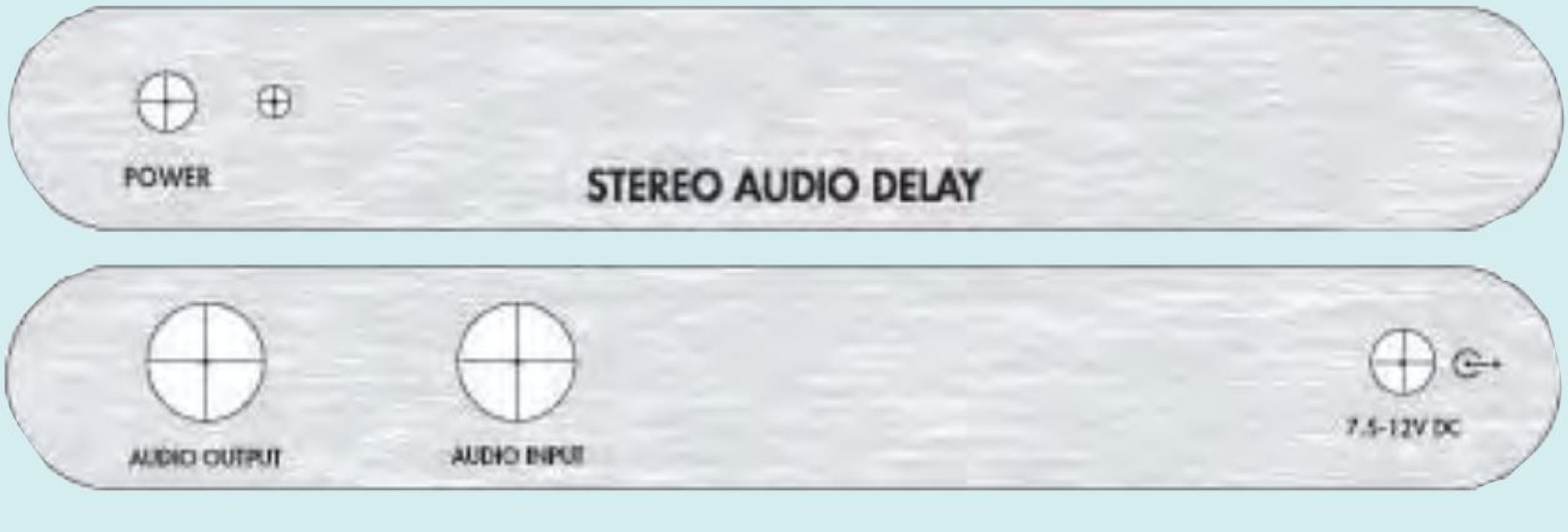
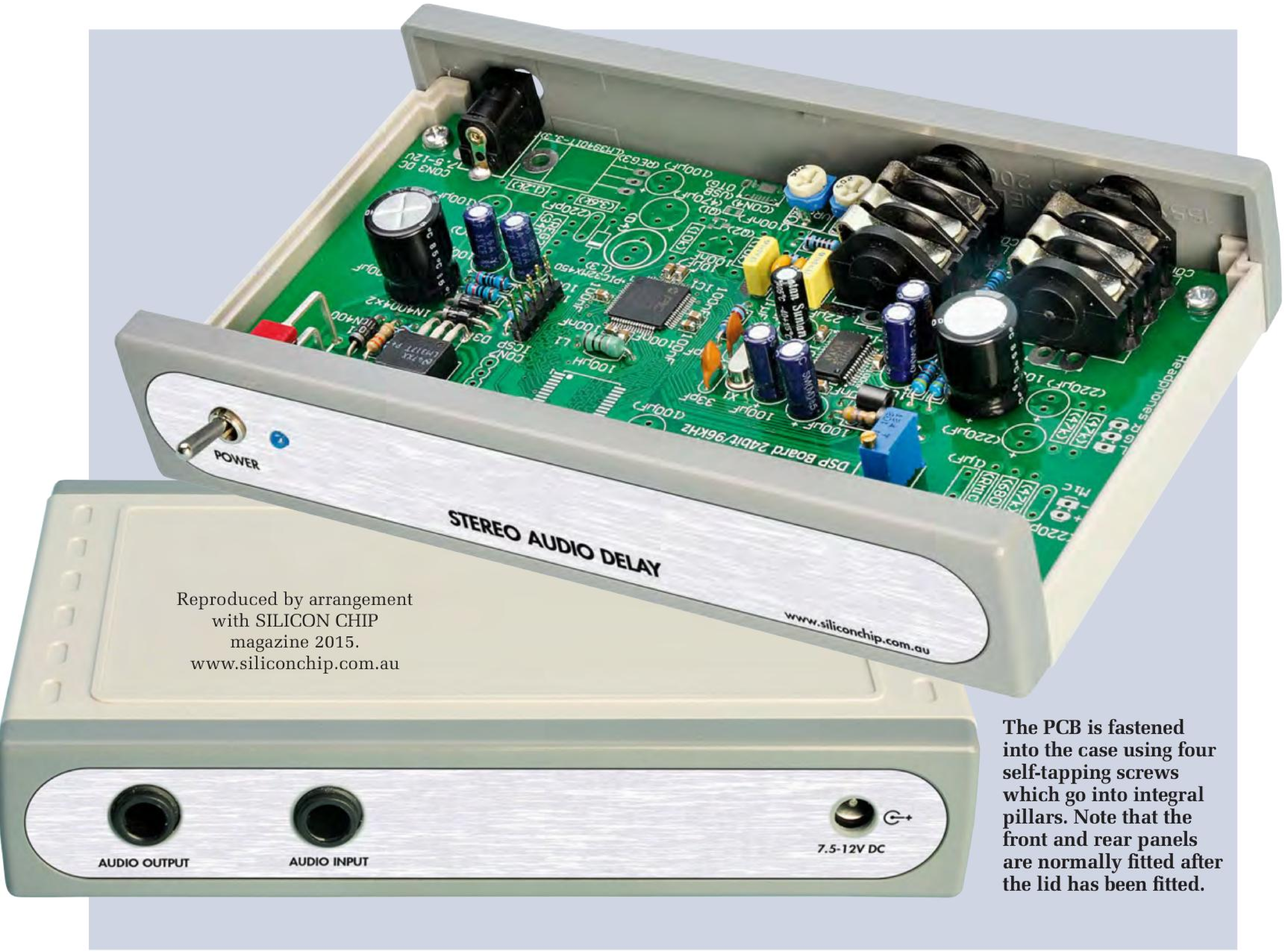


Fig.7: these two artworks can be copied and used as drilling templates for the front and rear panels. They can also be downloaded as a PDF file from the *EPE* website.



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The PCB is fastened into the case using four self-tapping screws which go into integral pillars. Note that the front and rear panels are normally fitted after the lid has been fitted.

size using a tapered reamer. That done, remove the templates and de-burr the holes using a counter-sinking tool or oversize drill bit. Any adhesive residue can normally be cleaned up with methylated spirits.

Check that the holes are large enough by test fitting the panels to the bare PCB. A new set of panel labels can then be printed onto photographic paper, attached to the panels using silicone adhesive and the holes cut out using a sharp hobby knife.

The assembly can now be completed by screwing the PCB to the bottom of the case using four No.4 × 6mm self-tapping screws, then placing the lid on top and snapping the front and rear panels on. If you have trouble fitting the panels over the connectors, enlarge the offending holes slightly. Note that the DC power socket is recessed; most DC power plugs are long enough to fit through the rear panel.

Using it

All that's left is to install the unit in its intended application and set the required delay. For PA systems, this can be a simple trial-and-error process whereby you incrementally increase the delay to get the best overall intelligibility at various points in the hall (or venue).

A similar procedure will be required where the unit is used to provide two separate delays.

Once adjusted, you can determine what the delay is actually set to by measuring either the frequency or the duty cycle at pins 4 and 5 of CON7. Even if the pin header is not fitted, you can simply 'poke' probes into the plated PCB holes.

A PWM signal is provided at each of these pins and its frequency in Hz is equal to the set delay in milliseconds (DC = no delay). The duty cycle varies from 0-99%, with 99% indicating maximum delay (ie, 0.64s or 6s, depending on whether IC3 is fitted).

If the unit is set up for dual mono delays, measure pin 4 to determine the left channel delay and pin 5 the right channel delay. Note that the accuracy of these readings depends on the exact frequency of crystal X1.

What's coming

That's all there is for the delay function. In the next instalment, we'll show you how to use the same hardware for echo or reverb. These functions are especially useful when used in conjunction with a microphone (for vocalists) or an electric guitar.

As such, we'll show you how to wire the unit up to a pedal, so that the effect can be switched on and off easily. We'll also show you how to reconfigure the unit to run from a 5V supply, in case you want to power it from a computer USB port or similar.

TechnoTalk

Something eerie in the ear

Mark Nelson

This month's column is about some people's amazing ability to hear sounds inaudible to others. Total nonsense? Not at all, so let Mark Nelson convince you that fact can sometimes be stranger than fiction. Or is it indeed utter tosh?

A COUPLE OF MONTHS BACK the cover of *New Scientist* magazine carried the intriguing headline 'The Man Who Hears Wi-Fi: Audio Hack Reveals A Hidden World'. I took the bait and bought the magazine to discover a fascinating tale. Frank Swain, the subject of the article, suffers from deafness and is a hearing aid user. But now he has hacked his hearing so he can listen in to the data that surrounds us. His iPhone has been modified to register, as an artificial audio signal, the level of Wi-Fi activity in his immediate environment. This 'sound picture' is then fed to his hearing aid.

Clever stuff?

With a grant from UK innovation charity NESTA, sound artist Daniel Jones and writer Frank Swain built an experimental tool for making Wi-Fi signals audible. Explains Swain: 'Running on a hacked iPhone, the software exploits the inbuilt Wi-Fi sensor to pick up details about nearby hotspots: router name, signal strength, encryption and distance.' Daniel Jones adds: 'The strength of the signal, direction, name and security level on these are translated into an audio stream made up of a foreground and background layer: distant signals click and pop like hits on a Geiger counter, while the strongest bleat their network ID in a looped melody. This audio is streamed constantly from the iPhone to a pair of hearing aids. The extra sound layer is blended with the normal output of the hearing aids; it simply becomes part of the soundscape.'

In-brain radio reception

Frank Swain requires additional tech to hear Wi-Fi, but some folk can hear radio signals in their head, without any electronics. In fact, many people claim to have heard radio signals, picked up on their tooth fillings or teeth braces when located close to a transmitter. The metalwork in their mouths acts as a rectifier-detector (check out 'rusty bolt effect' on Google) in the same way as a lump of galena works in an old crystal set radio. How the detected signals are converted to audible sound is less clear, however.

Someone with personal knowledge of this phenomenon is radio ham David Bartholomew (callsign WB6WKB). As reported in the Usenet group **rec.radio.amateur.misc**, he states: 'It's real. I attended a Field Day setup a few years ago, staged by the Westside Amateur Radio Club in Los Angeles. They had one of their stations inside a trailer, and the radio had an automatic antenna tuner. Well, somebody didn't ground the thing right. I was inside the shack about five feet from the radio when the operator said, '15 meters is dead; let's tune it up on 20.' He changed bands and hit the deadly little Automatic Tune button. The radio began buzzing as the tuner went to work. Also, I let out a scream as one of my teeth with a nice filling in it suddenly felt like a dentist was drilling in it with no anaesthetic! I ran from that trailer uttering obscenities and the pain vanished as soon as I got clear of the thing. Needless to say, I didn't hang around that particular shack much during the rest of the contest.'

Japanese spies betrayed

The admirable scourge of suspect urban legends, **snopes.com**, considers 'undetermined' the claim that the American comedienne Lucille Ball picked up radio transmissions on her fillings that led to the capture of Japanese spies. In 1942, the 'I Love Lucy' star had several temporary lead fillings installed in her teeth and driving home one evening from the MGM studios, she reported hearing music, even though the car radio was not turned on.

On another evening, in her words, 'It wasn't music this time, it was Morse code. It started softly, and then de-de-de-de-de-de. I stopped the car and then started backing up until it was coming in full strength. DE-DE-DE-DE-DE-DE! The next day I told the MGM Security Office about it, and they called the FBI or something, and sure enough, they found an underground Japanese radio station. It was somebody's gardener, but sure enough, they were spies.'

It's a great story and one that's unlikely to have been made up, so this too has the ring of confidence.

Golden ears experience

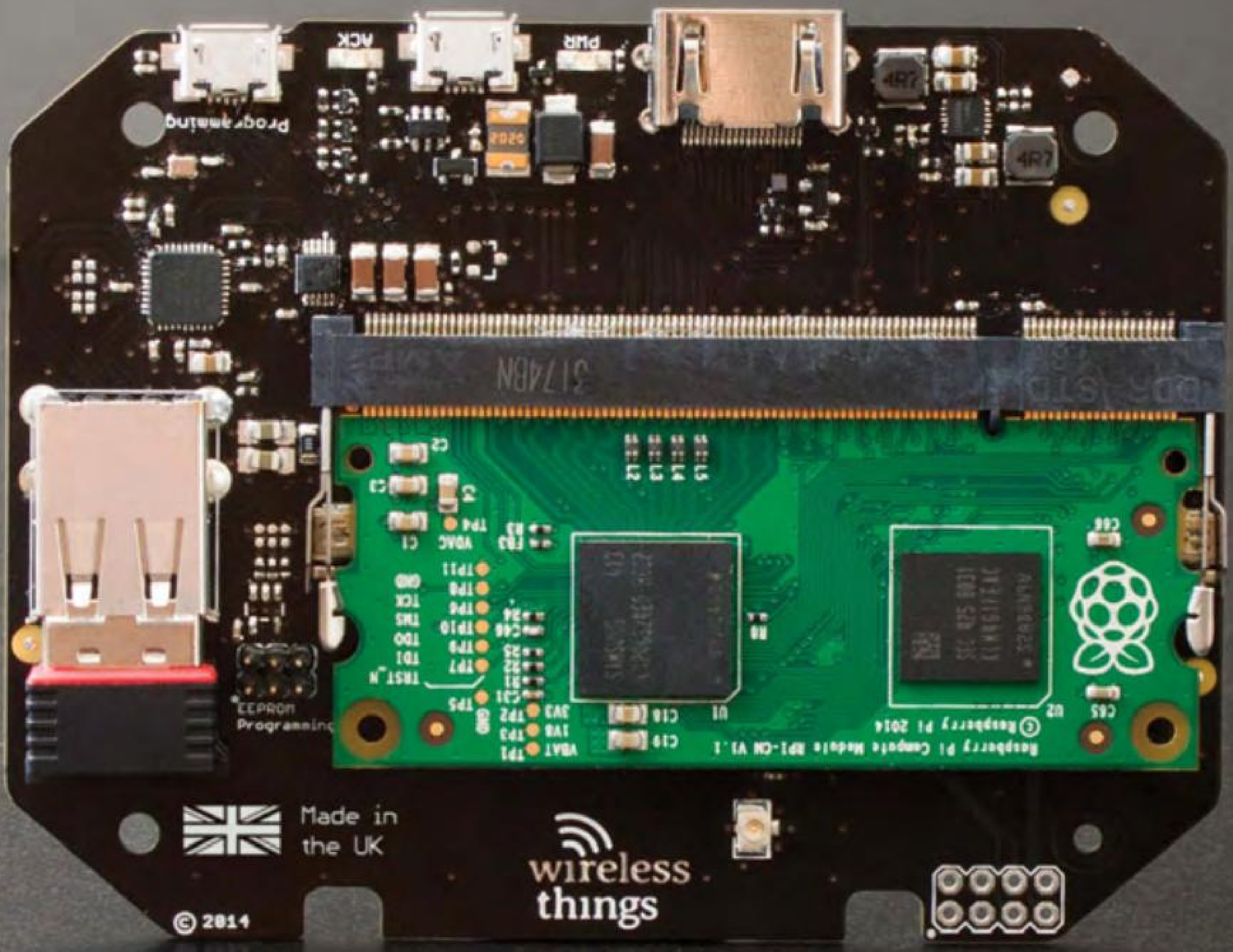
Next, acoustic feats that are even more amazing. A new range of 'audiophile grade' mains plug fuses is now available, from not one but three firms. You can even buy them conveniently on eBay at just £15 for a presentation box of three. Why should you invest in them? Well, 'to an audio or visual system, the AMR Gold Fuse will bring you fuller body, better definition and detail, not to mention reduced distortion'. What's more, the Gold Fuse has been 'independently tested in the audio and visual fields against the leading brands and proved to be one of, if not the best, fuse currently available to the performance-minded consumer.' It's well worth reading the impressively technical 'Specifications' printed (in gold text) on the inside of the presentation box lid: Silver Alloy Fuse Wire (it doesn't actually say the percentage of silver in the alloy); Low Inductance Design (because an inch of wire is usually dozens of henries, and a real issue at 50Hz – right?); Gold-Plated End Caps – see above; Non Magnetic (*NEVER* use magnetic fuses!)...

But *those* Gold Fuses sound abnormally – how can I put this? – 'cheap'. Far better to buy a SuperFuse from Russ Andrews at the value-for-money price of £25 each. The end caps are hand-polished and treated with DeoxIT 'contact enhancer' and finally, the SuperFuses are supplied with a DeoxIT 'Gold wipe' for treatment just before fitting. Actually, you can save money by splashing out five pence less on an IsoClean Power audio-grade fuse for audiophile performance, which 'will give your system an instant performance upgrade for a minimal cost'. What's more, 'each and every fuse is also thoroughly and accurately measured and checked in order to ensure the benefits to the end user are maximised.'

For some reason the old saying 'An audiophool and his money are soon parted' comes to mind, so I do hope each of these fuse suppliers provides a complimentary bottle of snake oil that customers can sniff delicately in order to better appreciate the improvement to their Hi-Fi systems.

Last, but not least, remember that your letters go to the editor, not me!

wirelessthings.net/openhardware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things
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STANDBY
ON
OFF

"Tiny Tim" Stereo Amplifier

Part 2

Leo Simpson and Nicholas Vinen

Having introduced this compact stereo Hi-Fi amplifier in our January issue, let's start building it. Here we describe how to assemble the amplifier board and power supply, and also how to prepare the case.

As explained earlier, this amplifier is a beef-up version of the *Hi-Fi Stereo Headphone Amplifier* and is suitable for driving a wide range of speakers – especially the *'Tiny Tim' Speakers* featured in our October issue.

Note that to complete the amplifier, some additional parts will be required beyond those specified in Part 1 – see the parts list in this article.

PCB modification

Start by assembling the main amplifier/preamplifer PCB. It's coded 01309111, measuring 198 × 98mm and is available from the *EPE PCB Service*. First, though, there is a little surgery required on the PCB tracks which will allow it to operate with higher power.

On the PCB overlay there are eight links shown. However, the PCBs purchased from the *EPE PCB Service* (and, presumably, any supplied in kits) will be double-sided so these links will already be in place, courtesy of PCB tracks.

However, these boards may also have top-side tracks connecting the points labelled 'A' to 'D' (near the heatsinks at lower left). If so, you will need to cut these (use a sharp knife to cut sections out of the tracks and then check, with a multimeter, that there is no continuity between the points).

If you have made your own board or yours is supplied as a single-sided type, you will obviously need to install the links. Use 0.7mm diameter tinned copper wire.

And regardless of whether yours is a single or double-sided board, you will need to cut the two tracks on the underside shown of the board, marked with red 'x's on the PCB overlay diagram. As before, use a sharp knife then check that there is no continuity between A and B, and C and D with your multimeter.

Now you can start fitting the components, starting with resistors, noting that two (both 680Ω) have ferrite beads slipped over their leads before they are soldered in place. Check each resistor against the colour-code table and also with a DMM set to ohms to ensure you have the right value. Note that you may want to leave the resistor pads labelled A and B unsoldered at this point, with the resistor leads left long; this will make it easier to join wires to them later.

With the resistors in place, follow with the 14 1N4004 diodes, taking

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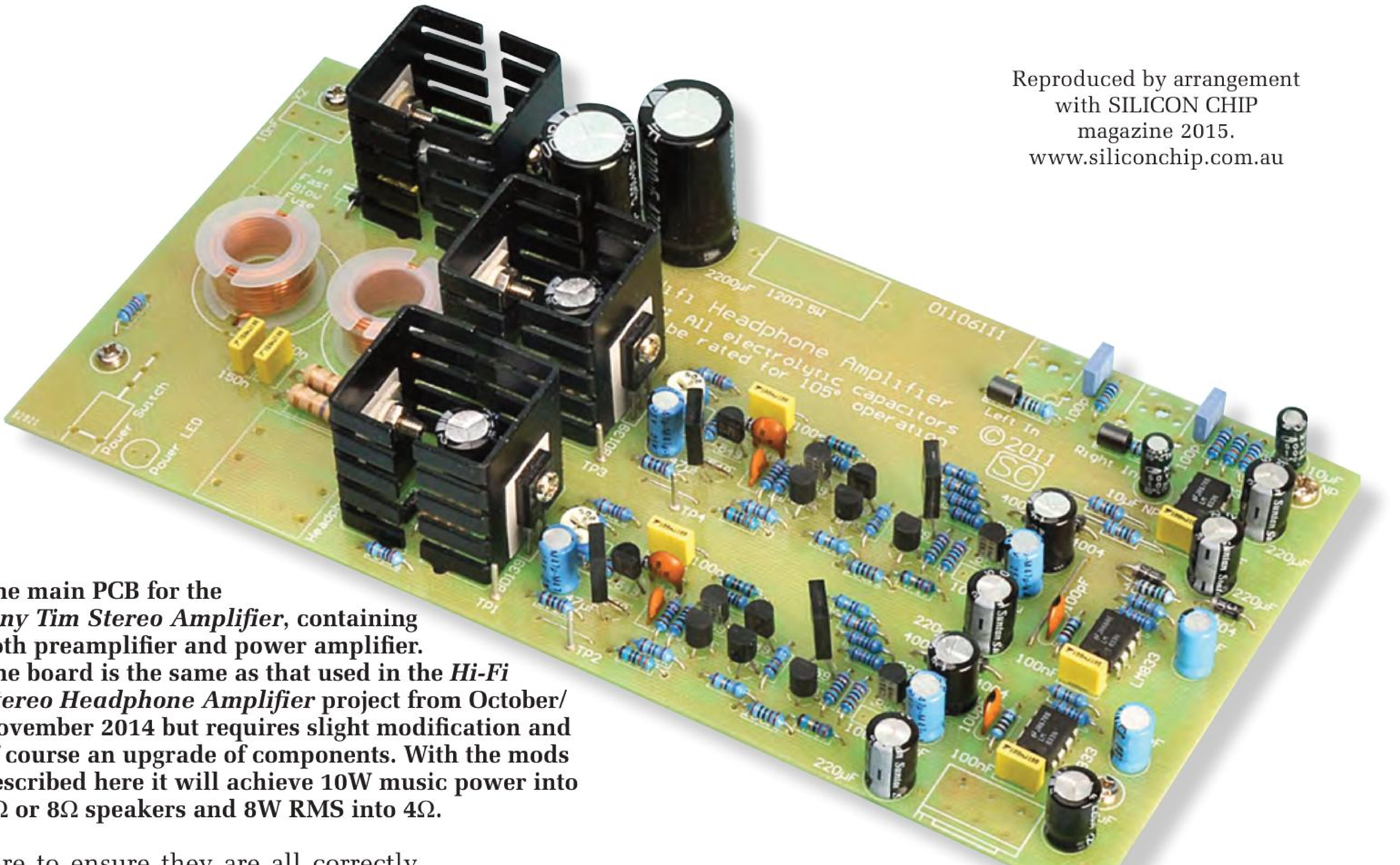


The main PCB for the *Tiny Tim Stereo Amplifier*, containing both preamplifier and power amplifier. The board is the same as that used in the *Hi-Fi Stereo Headphone Amplifier* project from October/November 2014 but requires slight modification and of course an upgrade of components. With the mods described here it will achieve 10W music power into 4Ω or 8Ω speakers and 8W RMS into 4Ω.

care to ensure they are all correctly oriented. In each case, the stripe faces to the left or the bottom of the board. The four BAT42/BAT85 small-signal Schottky diodes (D15-D18) near IC1 (upper-left) can then go in. Their orientations vary, so take care.

If you are using sockets for IC1-IC3, solder them in now with the notches to the right as shown. Alternatively, you can solder the ICs direct to the board with the same orientation.

The MKT and ceramic capacitors are next on the list, followed by the 16 small-signal transistors. There are three different types, so be sure to install the correct type at each location. Use a small pair of needle-nose pliers to crank the transistors leads so that they mate with the board holes and check that each transistor is correctly oriented.

The two 500Ω trimpots can now go in. That done, fit PCB pins at test points TP1-TP4 plus another two to support the tinplate shield between inductors L3 and L4. Then, mount the electrolytic capacitors, but leave the two 4700µF filter capacitors out for the time being. Note that four of the capacitors are labelled as 50V types (a higher rating such as 63V is fine). As with the resistors, the capacitor leads labelled C and D are best left unsoldered until later.

The four BD139/140 transistors which are not mounted on heatsinks can go in next. You will need to bend their leads to fit the triangular pad pattern originally intended for a TO-92 transistor, as shown on the overlay diagram and photos. The metal mounting faces of each pair face towards each other.

Note that some BD139/140 transistors may lack a metal face; in which case you will need to look at which side has the transistor type number printed on it (which is opposite the mounting face) and ensure that these sides face away from either other.

Winding the inductors

The two air-cored inductors (L3 and L4) are wound on small plastic bobbins. It is much easier to wind them if you make a winding jig, as shown in the panel.

To wind the first coil, initially secure the bobbin to the jig with one of its slots aligned with the hole in the end cheek. That done, feed through the hole about 20mm of a 1m-length of 0.8mm-diameter enamelled copper wire, then carefully wind on 20.5 turns before bending the end down so that it passes through the opposite slot in the bobbin. Trim the 'finish' end of the wire to 20mm (to match the start end), then secure the winding with a layer of insulation tape and remove the bobbin from the winding jig.

A 10mm-length of 25mm-diameter heatshrink tubing is used to finally secure the winding. Slip it over the outside and gently heat it to shrink it down (ie, be careful to not melt the bobbin).

The second coil is wound in exactly the same manner. Once it's finished, scrape the enamel off the leads on both inductors and tin them before fitting them to the PCB.

Further modifications

The tracks cut earlier allow us to reconfigure the power supply so that the output stages run off the unregulated ±20V rails – but to do that, we also need to run four insulated wires on the underside. It is simply a matter of connecting the pads labelled A-A, B-B, C-C and D-D.

To join A-A and B-B you can use light-duty wire because these only need to be able to carry enough current to power the preamplifier; even Kynar (wire wrapping wire) or bell wire is suitable. The two shorter runs, C-C and D-D, can carry in excess of 1A, so medium- or heavy-duty hook-up wire is more suitable.

Completing the PCB assembly

The tinplate shield between the two inductors can now be installed. This shield measures 35 × 15mm and can be cut from the lid of a large tin (or

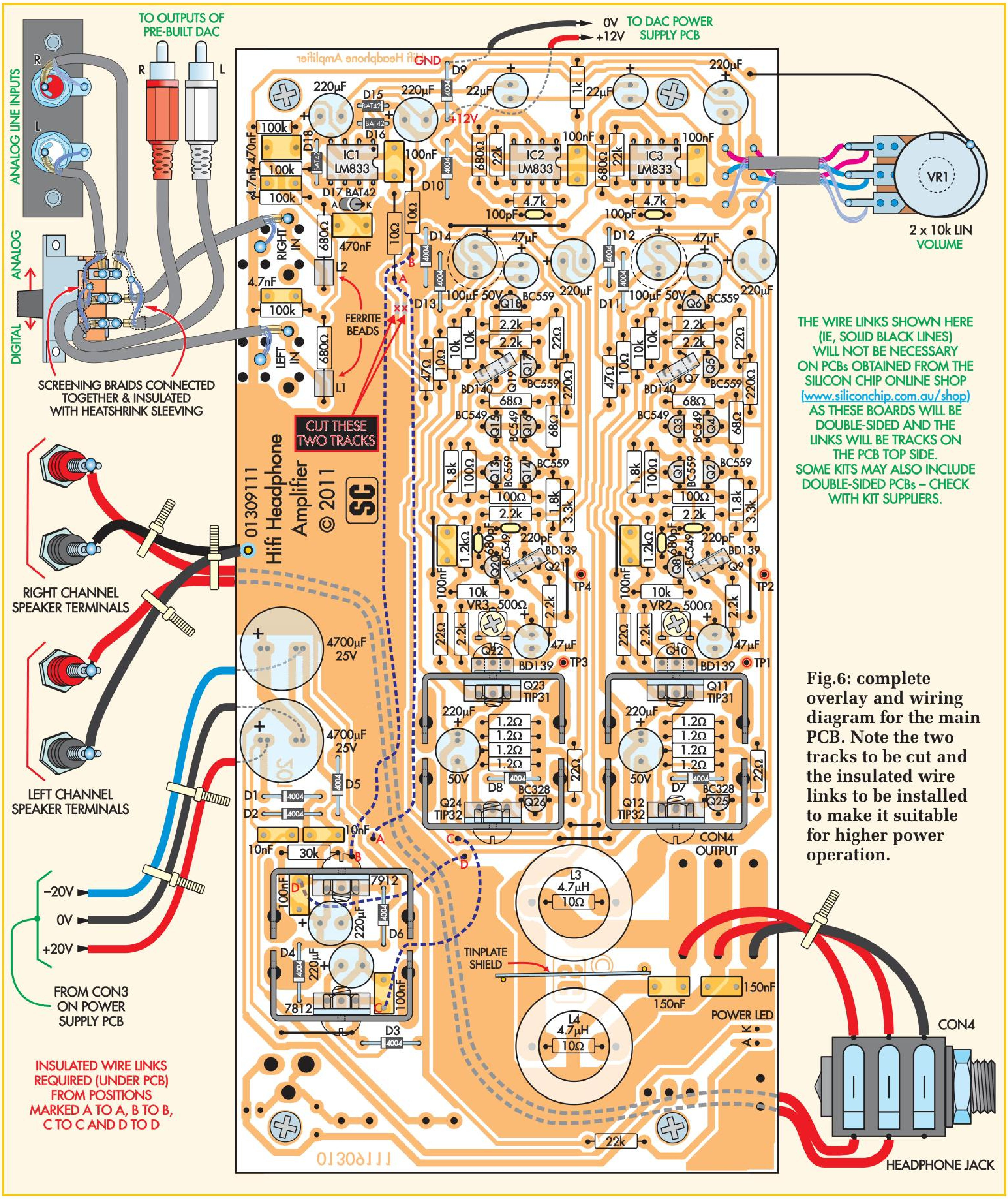

TO OUTPUTS OF PRE-BUILT DAC
0V +12V TO DAC POWER SUPPLY PCB
ANALOG LINE INPUTS
R
L
ANALOG
DIGITAL
RIGHT IN
LEFT IN
SCREENING BRAIDS CONNECTED TOGETHER & INSULATED WITH HEATSHRINK SLEEVING
FERRITE BEADS
CUT THESE TWO TRACKS
01309111 Hifi Headphone Amplifier © 2011
SC
RIGHT CHANNEL SPEAKER TERMINALS
LEFT CHANNEL SPEAKER TERMINALS
4700µF 25V
–20V
0V
+20V
FROM CON3 ON POWER SUPPLY PCB
INSULATED WIRE LINKS REQUIRED (UNDER PCB) FROM POSITIONS MARKED A TO A, B TO B, C TO C AND D TO D
IC1 LM833
IC2 LM833
IC3 LM833
7912
7812
TINPLATE SHIELD
L3 4.7µH 10Ω
L4 4.7µH 10Ω
CON4 OUTPUT
POWER LED
150nF
22k
VR1
2 x 10k LIN VOLUME
THE WIRE LINKS SHOWN HERE (IE, SOLID BLACK LINES) WILL NOT BE NECESSARY ON PCBs OBTAINED FROM THE SILICON CHIP ONLINE SHOP (www.siliconchip.com.au/shop) AS THESE BOARDS WILL BE DOUBLE-SIDED AND THE LINKS WILL BE TRACKS ON THE PCB TOP SIDE. SOME KITS MAY ALSO INCLUDE DOUBLE-SIDED PCBs – CHECK WITH KIT SUPPLIERS.
CON4
HEADPHONE JACK
Q23 TIP31
Q24 TIP32
Q11 TIP31
Q12 TIP32
VR2 500Ω
VR3 500Ω
TP1
TP2
TP3
TP4

Fig.6: complete overlay and wiring diagram for the main PCB. Note the two tracks to be cut and the insulated wire links to be installed to make it suitable for higher power operation.

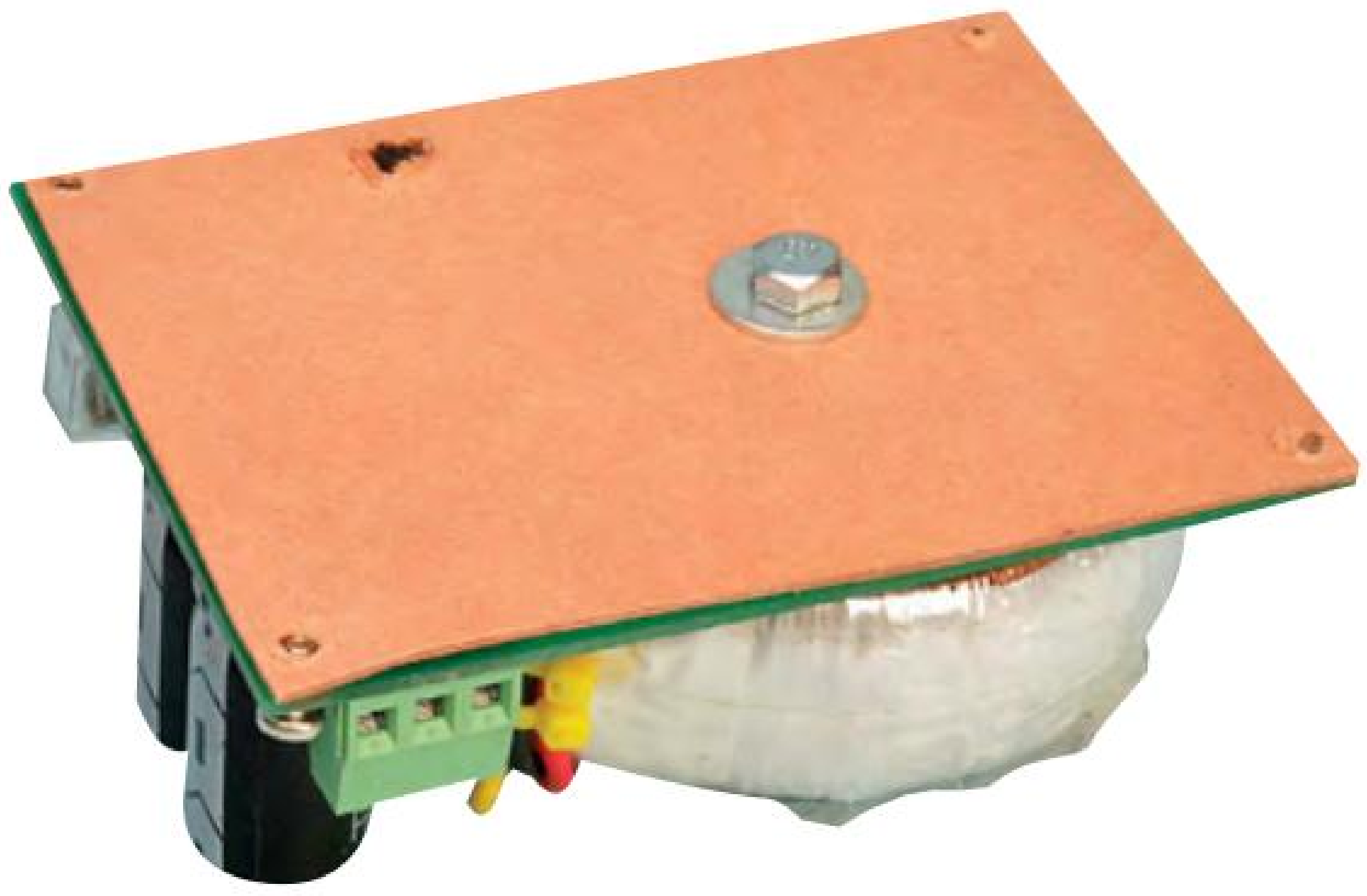
similar) using tin snips. File the edges smooth after cutting, then temporarily position it between the two PC pins and mark their locations.

That done, hold the shield in an alligator clip stand and melt some solder onto either side at the marked locations. It may take 10 seconds or more to heat it enough for the solder to adhere.

Finally, flow some solder onto the tops of the two PC pins before fitting the shield in position and remelting the solder to secure it.

Mounting the heatsinks

The two regulators and six power transistors are mounted on six large flag heatsinks. These have two posts which pass down through the PCB for support. Two of the heatsinks have two transistors mounted on



Here's the underside of the power supply board, completely covered with a sheet of fibre insulation.

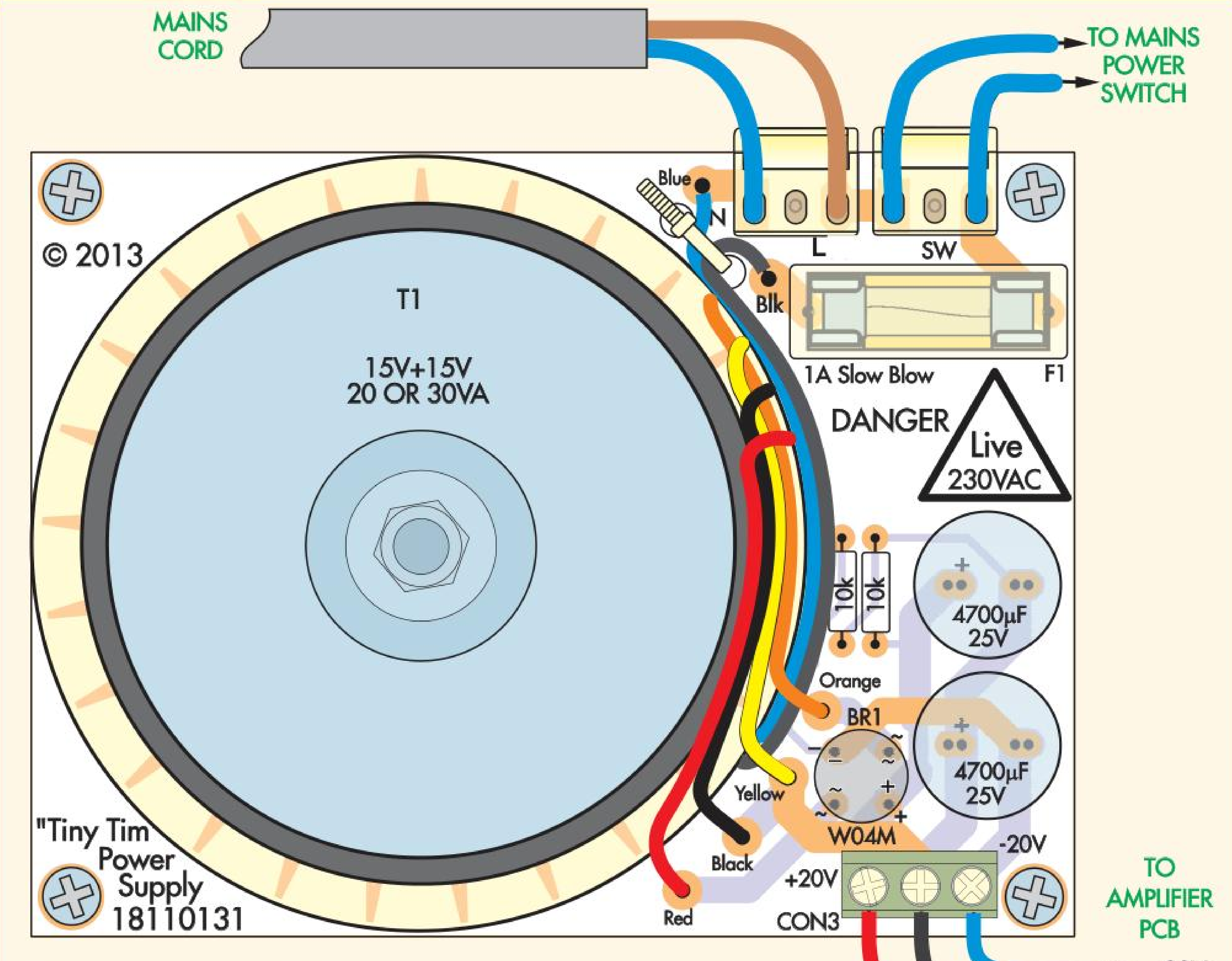
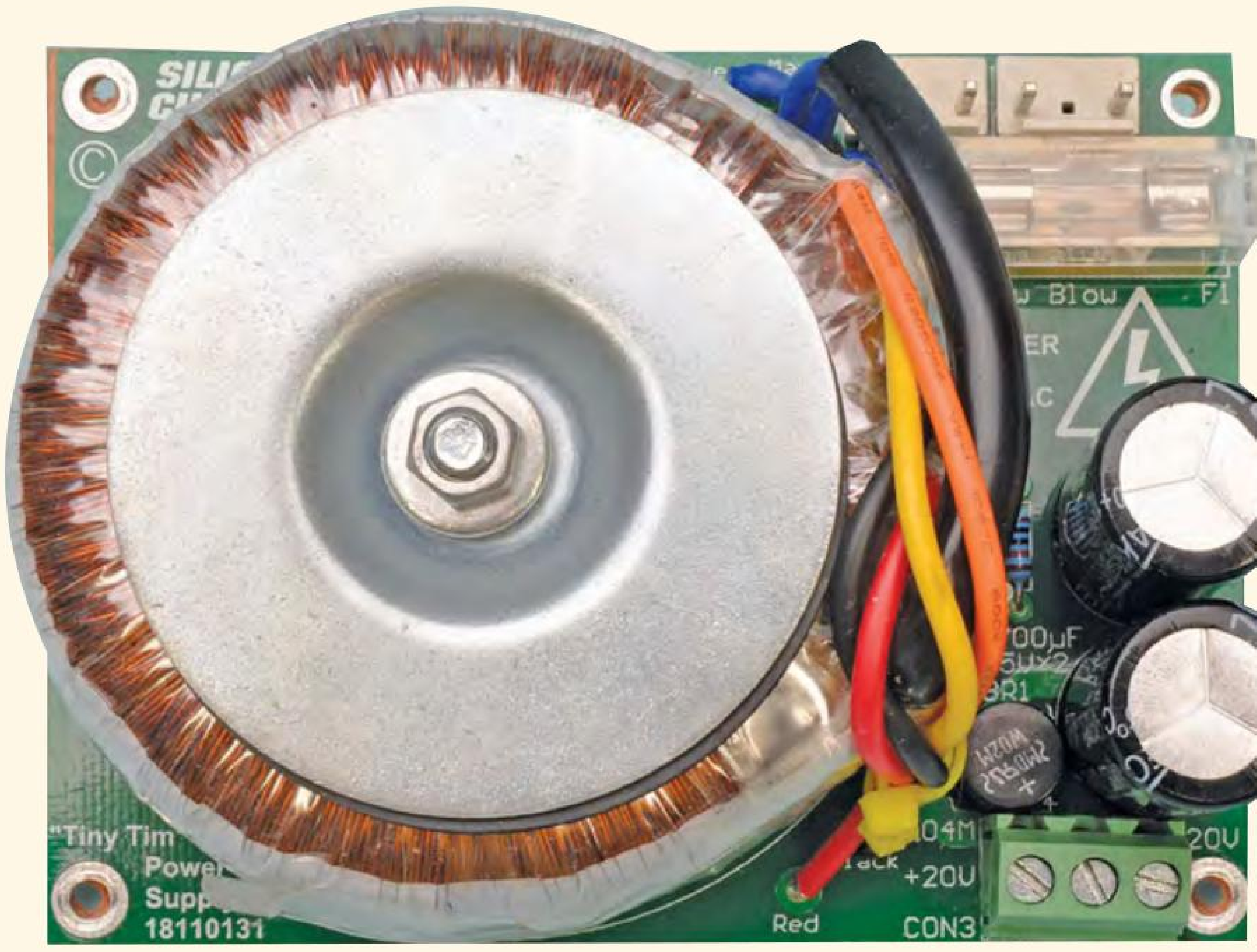


Fig.7: same-size PCB component overlay with matching photo below. This PCB can also be used as a general-purpose supply with appropriate transformer.



them, one each side (see overlay and photos).

Start by loosely fitting the 7812 and 7912 regulators to their heatsinks. Note that, in each case, the regulator's metal tab must be isolated from its heatsink using an insulating bush and silicone washer.

That done, fit the 7812 regulator assembly through the lower set of holes just above CON3 and D3. If the heatsink has 'solderable' pins, flip the board over and solder one, then double-check that it is sitting perfectly flush with the board before soldering the other. Since you have to heat up quite a bit of metal, it could take 15 seconds or more before the solder adheres to the post.

Alternatively, if the heatsink doesn't have 'solderable' pins, use pliers to bend the tabs outwards far enough so that it is secured to the board.

Having secured the heatsink, check that the insulating washer is properly aligned with the regulator and tighten the mounting screw. The regulator's leads can then be soldered. Repeat this procedure for the 7912 regulator.

The two TIP32 power transistors (Q12 and Q24) are mounted in identical fashion to the regulators. By contrast, the heatsinks for the two TIP31 power transistors (Q11 and Q23) have the BD139 V_{BE} multiplier transistors mounted on the other side. Be sure to insulate all the transistors from the heatsinks using silicone washers and insulating bushes as necessary.

The power connector, power switch and LED, input and output sockets and volume control potentiometer are not fitted to the board; instead, most of them are chassis-mounted and connected with flying leads We'll get to that later. First, let's assemble the power supply.

Power supply

Before fitting any components, use the power supply PCB as a template to cut a sheet of fibre insulation (often sold as Presspahn or Elephantide) to 100 × 75mm and drill through the four mounting holes to make corresponding holes in the Presspahn sheet. Also make a hole corresponding with the transformer mounting hole and enlarge this to 5.5mm diameter.

Now begin assembly, following the overlay diagram of Fig.7. Fit the two resistors, then the bridge rectifier: make sure its '+' symbol lines up with that shown on the PCB overlay. Follow with the terminal block (wire entry holes towards board edge) and then the fuse holder.

We need to install the two pin headers next, but there's a bit of a trick here. In the January issue, we showed the power switch connected between the neutral pin of the mains power plug and the transformer primary/fuse. While this will work, it means that the transformer and fuse are live even when the power switch is off.

Of course, when opening up the unit for any reason (eg, to replace the

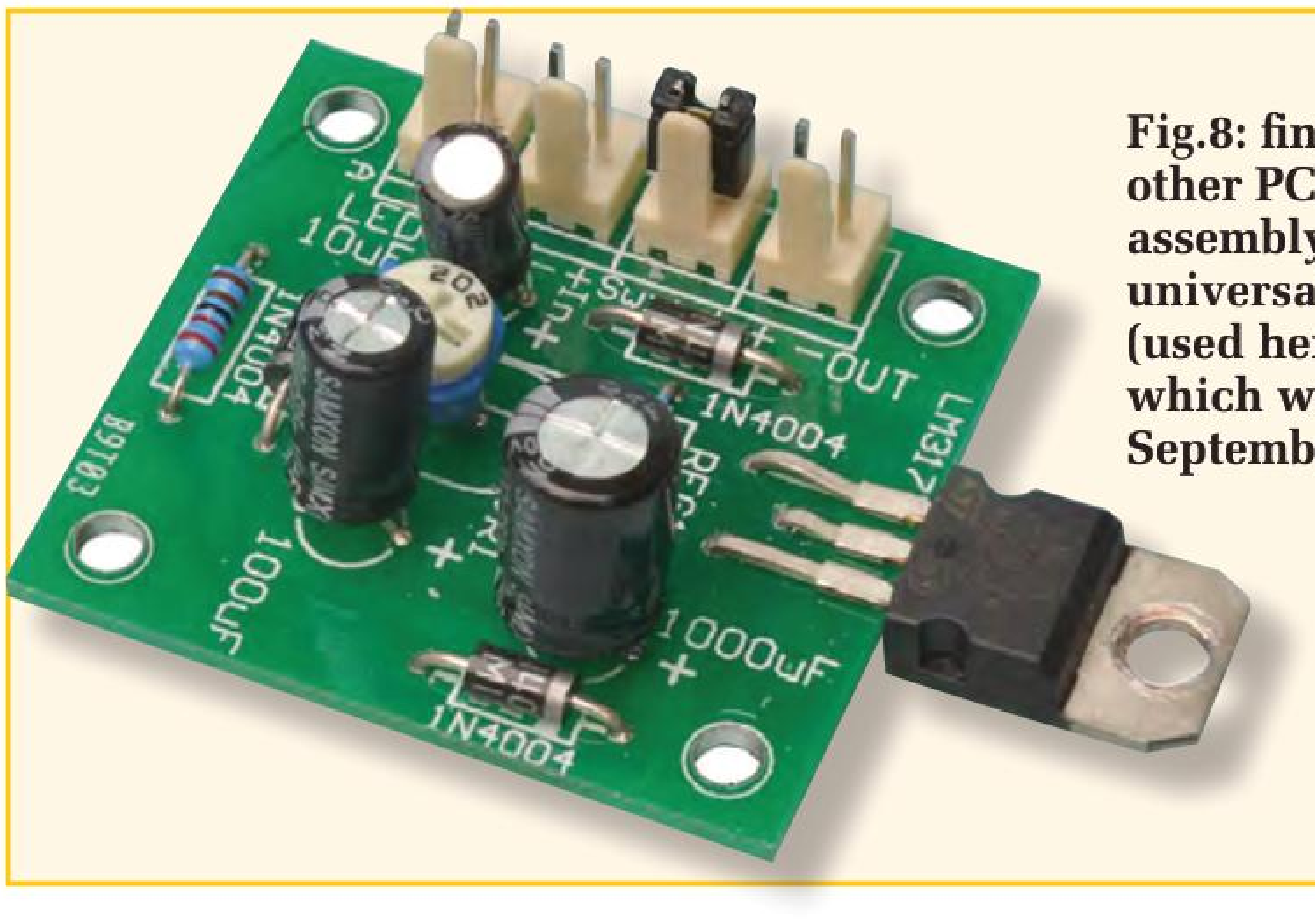
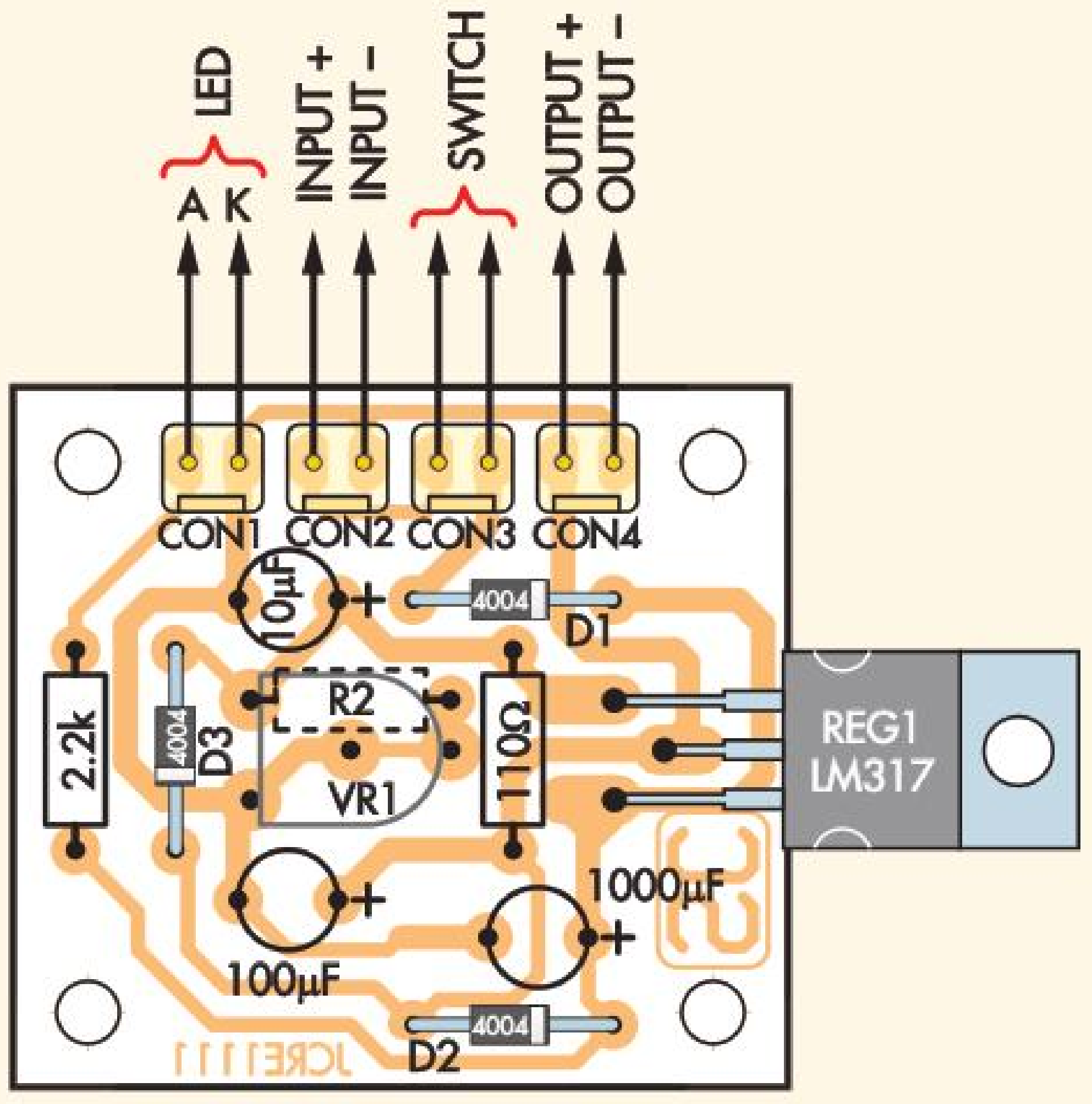


Fig.8: finally, the only other PCB which requires assembly, the *MiniReg* universal power supply (used here to power the DAC) which we published in the September 2013 issue.



fuse) it is always vital to ensure that it is unplugged, but in case somebody fails to do this, it is safer to have the switch between the mains plug live pin and the rest of the circuit. Note that it's possible for mains live and neutral to be swapped in house wiring, so this doesn't guarantee safety (hence the advice to always unplug a device before servicing it) but this is a safer arrangement most of the time, ie, when the house wiring is correct.

Now, since we're recycling the mains cord from a set-top box (or whatever other device you decide to rat), we don't know how it's wired. We checked two set-top boxes – both from the same manufacturer – and found that the mains cords were wired opposite to each other. So you will need to set your DMM on continuity mode and work out which pin of the header plug is wired to live (normally indicated with an 'L' for 'live' (or possibly 'A' for 'active) moulded into the plastic mains plug housing).

Once you've determined that, you can install the two pins headers with an orientation such that the live wire will go to the terminal marked 'L' on the board (ie, the one directly adjacent to the switch header). This is easier than trying to swap the pins to the polarised plug.

With the two headers in place, connect the mains cord to the left-hand header (leave the other end unplugged!) then double-check that the live pin on the plug is electrically connected to the left-hand pin of the switch header. If not, you will have to remove the left-most header and re-install it the other way around. Once you have verified that, fit the two electrolytic capacitors.

Now, before mounting the transformer, feed a cable tie through one of the two large holes at upper-right and then back up through the other, so that it passes under the board in the space between them. Make sure it's the right way around to do the tie up later, then place the sheet of Presspahn you prepared earlier under the board and feed the transformer mounting bolt up through this and the hole on the PCB.

Check that the corner screw-holes more or less line up and then slide the transformer's rubber pad over the bolt, place the transformer on top (with wires exiting on the top side) and use the rest of the mounting hardware supplied with the transformer to loosely hold it in place. Typically, this consists of another rubber pad, a metal dish, a spring washer, a flat washer and a nut.

Rotate the transformer so that the wires line up with the wire pads on the right-hand side and then tighten the nut (but not too tight!). How you proceed depends on which transformer you are using.

Transformer type 'A'

In some transformers the primary and secondary leads will need to cross over to reach the appropriate pads.

Winding jig for inductors

The winding jig consists of an M5 × 70mm bolt, two M5 nuts, an M5 flat washer, a piece of scrap PC board material (40 × 50mm approx.) and a scrap piece of timber (140 × 45 × 20mm approx.) for the handle.

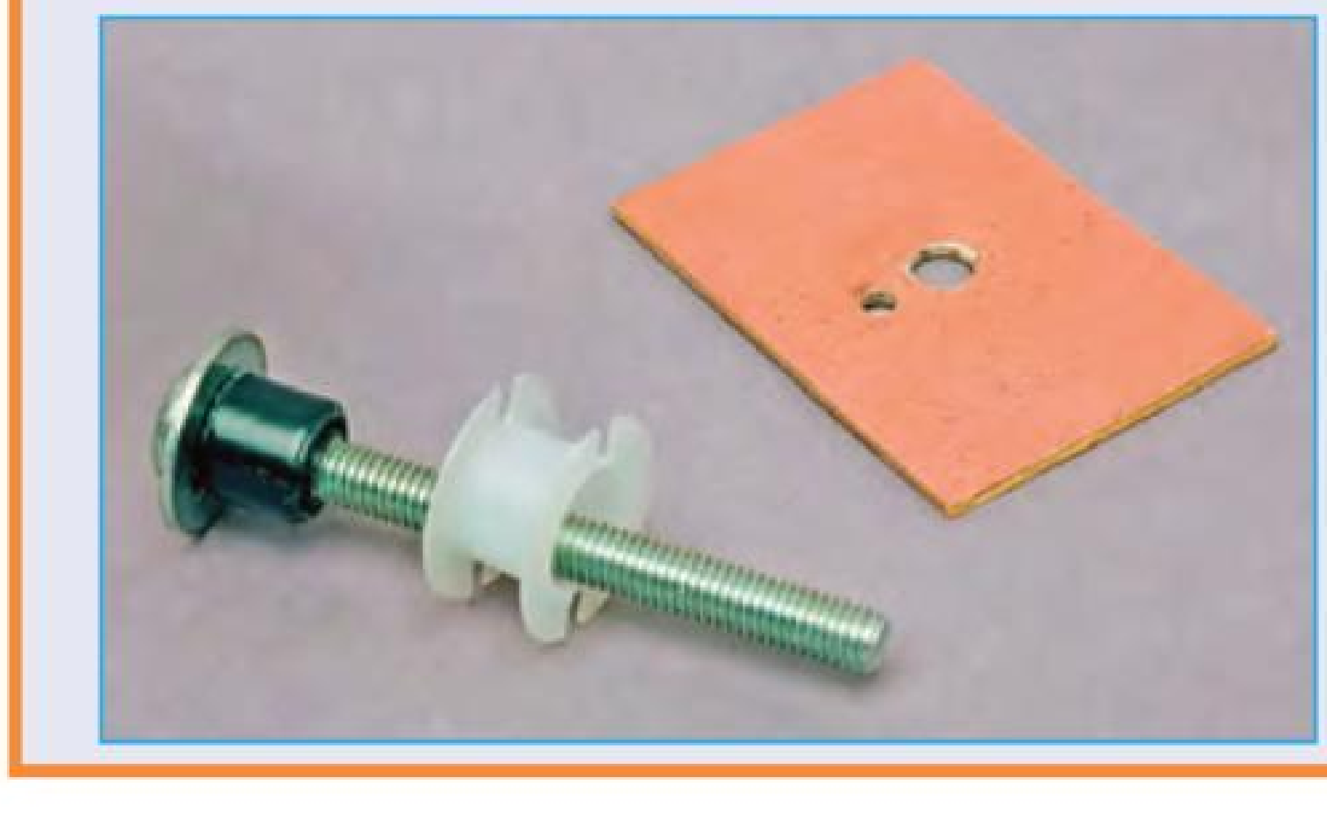
The flat washer goes against the head of the bolt, after which a collar is fitted over the bolt to take the bobbin.

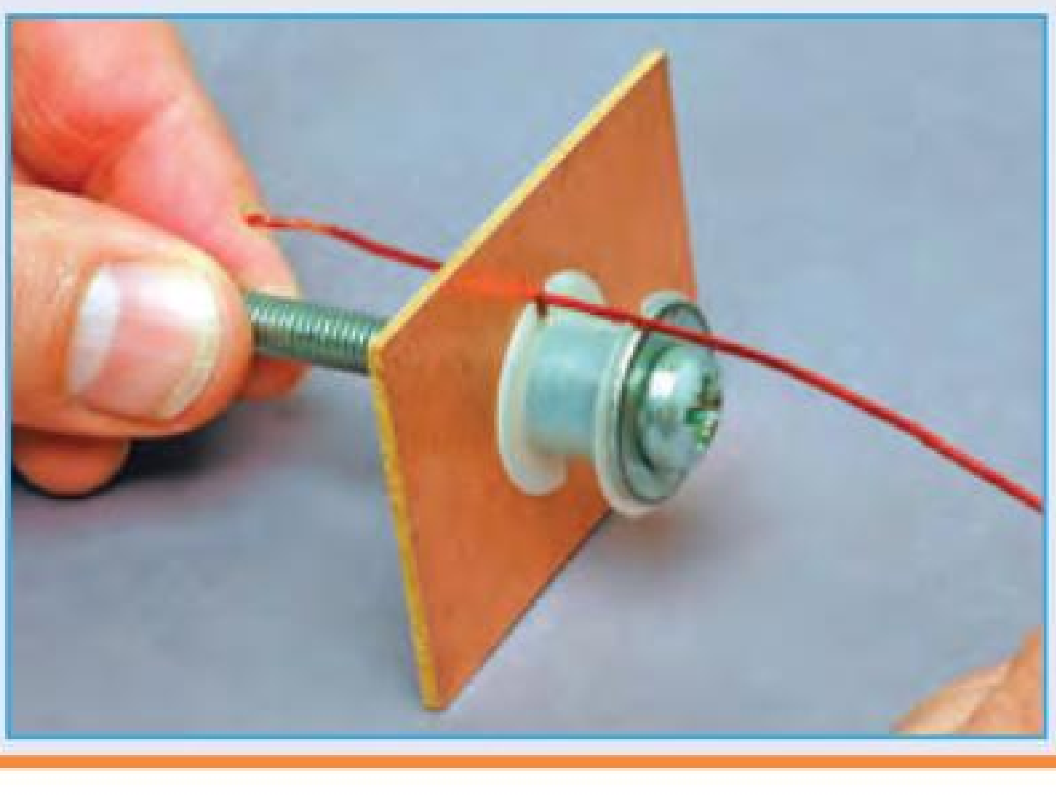
This collar should have a width that's slightly less than the width of the bobbin and can be wound on using insulation tape. Wind on sufficient tape so that the bobbin fits snugly over this collar.

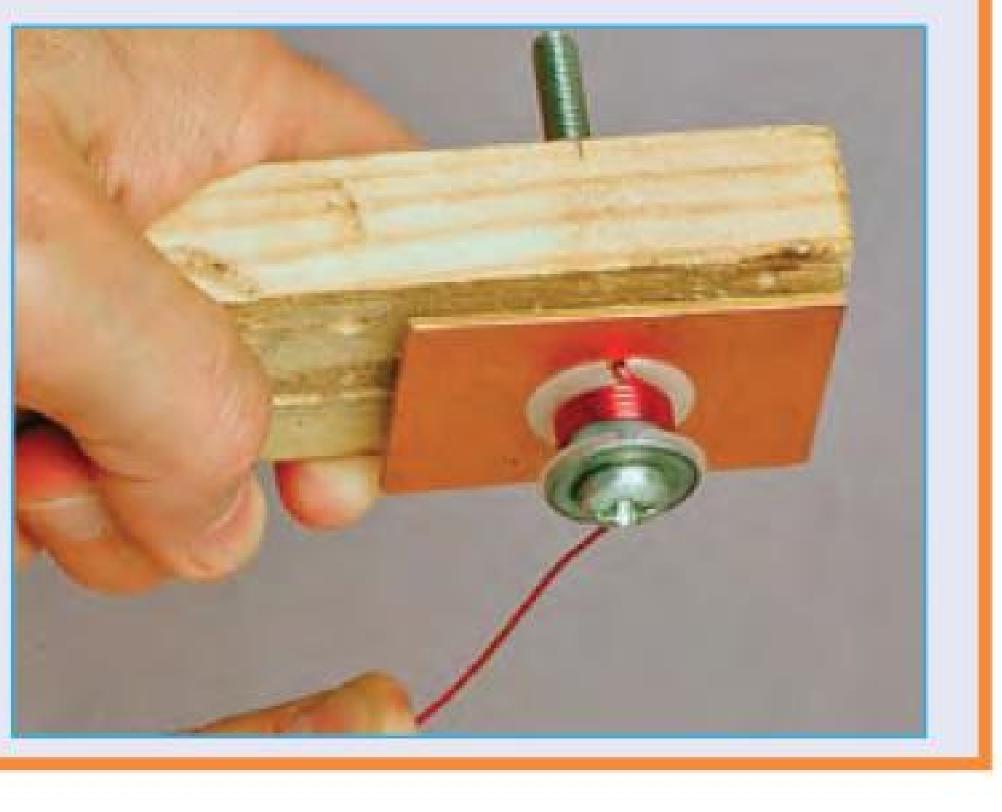
Next, drill a 5mm hole through the centre of the scrap PC board material, followed by a 1.5mm exit hole about 8mm away that will align with one of the slots in the bobbin.

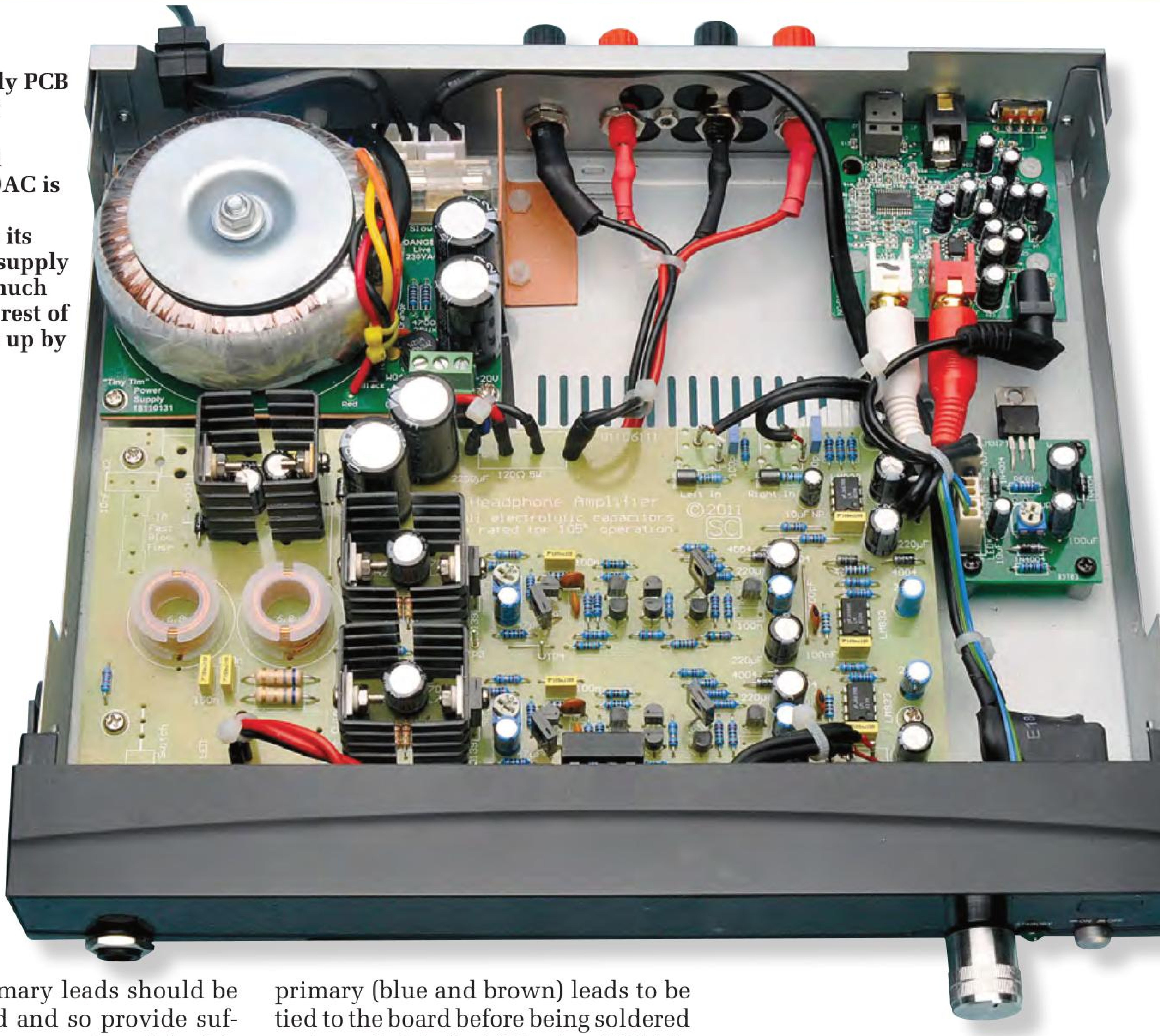
The bobbin is then slipped over the collar, after which the PC board 'end cheek' is slipped over the bolt. Align the bobbin so that one of its slots lines up with the exit hole in the end cheek, then install the first nut.

The handle is then fitted by drilling a 5mm hole through one end, then slipping it over the bolt and installing the second nut.









The power supply PCB is in the left rear corner, with a protective shield alongside. The DAC is in the opposite rear corner with its *MiniReg* power supply in front. Pretty much the whole of the rest of the case is taken up by the main PCB.

Luckily, the primary leads should be double-sheathed and so provide sufficient insulation to remain safe in this configuration.

Trim both the primary and secondary leads to length so that they reach their respective pads, leaving a little bit of slack and allowing for the fact that we are going to tie the primary leads down to the PCB before soldering them to the two pads. (check this by pushing them down onto the PCB with a finger, between the two tie holes, then arching them over to reach the solder pads.)

The secondary wires are colour-coded and go to the appropriate labelled pads at the lower-right of the PCB. You will probably need to trim these to slightly different lengths so that they will all reach their respective pads.

Transformer type 'B'

This type of transformer has the opposite wiring arrangement, so the primary and secondary leads do not need to cross over. Note that the colour coding is often different though; the white lead goes to the pad labelled 'yellow' while the others match up with their respective colours. You will need to allow a bit of extra length for the primary (blue and brown) leads to be tied to the board before being soldered to the pads labelled 'Blue' and 'Bl.' (it doesn't matter which goes to which).

Finishing the power supply

With the transformer leads trimmed and stripped, run the two primary leads through the cable tie you inserted earlier and do it up tight, then trim off the excess length. Solder all six leads to the appropriate pads, as explained above. Use two or three more cable ties to lace the secondary leads together so that should one break loose, it won't go floating around (and also to contain the magnetic field as much as possible).

You can now fit the four tapped spacers with the PCB and fibre insulation panel sandwiched in between. Use a nylon M3 screw in the upper-right corner, near the mains tracks, to ensure that a metal screw in the other end of the nylon spacer can't possibly make a connection through to the top of the board, where a stray wire could make the chassis live.

Insert a 1A slow-blow fuse into the holder and clip the top cover on. We'll test the power supply board later once it's in the case.

DAC power supply

We're using the *MiniReg*, described in the September 2013 issue of *EPE* to power the DAC, which runs off 6V DC at about 50mA. The *MiniReg* is fed from the 12V rail from the amplifier via the 2-pin plug soldered earlier. Follow the instructions in the September 2013 issue to assemble it. Don't worry about adjusting the output voltage, we can do that later.

You will need to make up a short (~50mm) 2-wire cable with a polarised header plug on one end and a 2.5mm inner diameter DC jack plug at the other end, to suit the DAC. This should be wired so that the inner conductor of the DC plug is positive. Refer to the *MiniReg* instructions to see which pin is the positive output and which is the negative. You will also need to short out the switch terminal (eg, with a jumper shunt).

The amplifier power indicator LED can also be run from the *MiniReg* and again this will require a 2-core cable with a polarised header plug at one end. Make this one a bit longer – say

100mm. Cut the LED leads short and solder the other end of the wires to these, with the cathode (flat side of LED lens) going to the terminal marked 'K' on the *MiniReg* PCB. Put these cable assemblies aside, for now.

Wiring

Cables for power, signal input and output leads must be soldered to the amplifier board, along with shielded cable to connect to the volume pot. While you could solder these wires directly to the board, doing so with everything already in the case is awkward. Hence, we fitted PC pins to most of these pads and soldered the wires to these later.

There are a total of 17 required – two for each input, three for the outputs, six for the potentiometer connections, three for the power supply wires and one for the speaker ground returns. However, upon reflection, we recommend soldering the power supply wires directly to the underside of the board, leaving 13 PC pins to fit.

Solder the pins in now, to the pads shown on the overlay diagram. Note that most of these holes are much larger than required for PC pins and some will let the whole pin pass through. You will need some sort of a clamp (eg, self-closing tweezers) to hold the pins in while you solder them.

For the power supply, solder 100mm lengths of heavy-duty wire to the 4700µF capacitor terminals. We have left fitting these capacitors until now so that you can wind the wire around the leads before soldering. Colour code the wires as shown.

Two more black heavy-duty wires then need to be soldered to the large ground plane area above these capacitors, for the speaker outputs. If you have a commercially-made board, you will need to scrape away some of the solder mask to allow this. If you like, you can drill a hole through the board and feed the wires in from the top and you can even fit a PC pin or two so the wires can be later soldered to the top of the board, if you want to.

You will also need to connect wires to run the DAC from the regulated +12V rail on the amplifier board. Take light-duty figure-8 cable about 50mm long (or two strands from a ribbon cable) and crimp/solder them into a 2-way polarised header plug. The other ends go to the pads shown in Fig.7, with 12V to pin 1 of the plug. A pin 1 indicator is normally moulded into the plastic plug housing.

Parts List (in addition to those listed in Part 1)

17 PCB pins
2 chassis-mount RCA sockets, one red and one white (or black)
1 panel-mount DPDT miniature slide switch
1 sheet fibre insulation (Presspahn or Elephantide), min 100 × 115mm
1 100mm length 8mm diameter black heatshrink tubing
1 200mm length 5mm diameter black heatshrink tubing
4 M3 nylon tapped spacers, various M3 nylon nuts (for DAC installation)
6 M3 × 10mm nylon machine screws
2 M3 × 6mm nylon machine screws
4 M3 × 5mm machine screws
3 M3 nylon nuts
2 M2 × 10mm machine screws and nuts
1 jumper shunt
3 2-pin polarised header plugs with crimp pins
20 small cable ties
3 small adhesive wire saddles/clamps
1 100mm-long, 8mm-diameter red heatshrink tubing
1 panel, 2mm plastic or 1mm aluminium – to cover rear panel of case
1 5mm LED bezel clip (optional)

Chassis preparation

A number of holes must now be drilled in the front, rear and base of the case, to attach the various connectors and mount all the modules. Start with the rear panel which needs holes or cutouts for the four speaker terminals, analogue RCA input sockets, analogue/digital selector switch and DAC inputs.

If you are using a case which originally housed a commercial piece of equipment (in our case, a set-top box), there will be many holes in the rear panel, most of which are not in the right location to re-use. The simplest way to solve this is to attach a new rear panel on top of the existing one, covering these up, which you can then drill and cut new holes in.

This panel can be metal or plastic, providing it is strong enough. We used a 2mm-thick plastic front panel from an instrument case that we had spare. Don't use thinner plastic as it isn't strong enough. A sheet of aluminium or tinplate is also suitable.

Cut the panel to the same size as the rear panel of your case, or at least large enough to cover up all the holes except that for the mains cable. Place this over the rear of the case and drill at least two 3mm holes through both. We put one at the end near the mains cable and another in the middle.

Feed through short machine screws and tighten these on to nuts to hold the panel in place. If one of the holes is near where the mains power supply will go, use a nylon screw and nut there.

You can now mark out the positions for the four binding posts, which should go near the middle of the rear panel, but not too close to the power supply mounting location – leave at least 10mm separation. We spaced them apart by about 20mm, with 5mm extra between the two pairs; if you put them much closer together than this, it makes connecting wires awkward.

Now mark positions for the TOSLINK and RCA socket inputs of the DAC board in the right-hand rear corner, as well as a rectangular cut-out for its selector switch to fit through. Since this switch body sticks out further than the TOSLINK connector, a slot will need to be cut to fit the whole thing through.

We elected to place the stereo RCA analogue input sockets and analogue/digital selector slide switch underneath the DAC inputs as there wasn't enough room in our case to place them side-by-side. You may want to do the same. In this case, make sure the holes for the DAC inputs and switch are towards the top of the case.

With the positions for all these connectors marked out, you can start by drilling pilot holes right through both the original rear panel and the new panel on top. Enlarge the holes for the binding posts and RCA sockets until the connectors fit through. Ideally, the binding posts and RCA connectors should be a snug fit.

The TOSLINK input, DAC selector switch and analogue/digital selector switch require rectangular cut-outs, and these are too small to easily nibble so you will probably have to drill a row of holes in each case and then slowly file it into a rectangle using needle files. You may find it easier to temporarily remove the new rear panel and file holes in the two panels separately before re-fitting it. Note that it's more important that the holes are neat in the outer panel than the inner one.

Test-fit the DAC board and make sure that it can be butted right up against the rear panel. For the analogue/digital selector slide switch you will need to file a slot for its actuator as well as two small mounting holes for screws. Once you have it in place do the screws up and check that the slot is large enough for it to smoothly slide to the end stops in both directions. Make sure to de-burr all the holes on both sides before fitting the connectors.

Front panel

You will also need to drill some holes in the front panel, or if possible, enlarge existing holes. Make sure you don't compromise the insulation for the existing mains switch when doing so as you will want to re-use it.

As you can see from the photos, we drilled a hole at the left end for a 6.35mm headphone socket and enlarged existing holes at right, near the power switch, for the 16mm volume control pot and 5mm power LED. You may also have to cut away some of the internal structure of the front panel in order to get these to fit. We used a plastic bezel to make the power LED a snug fit in the hole, then glued it in place using hot melt glue; you could also use silicone sealant.

If any holes are remaining in the front panel near the mains switch, file a piece of plastic to the shape of each hole and glue it in place. We used black plastic, to match the existing front panel, and glued them with cyanoacrylate ('super glue'). As you can see, the resulting seams are quite subtle.

Module mounting holes

The next step is to drill a series of 3mm holes in the bottom of the case for mounting the various modules. First, place the amplifier board near the front-left corner and mark out its four corner hole positions in the base. Then drop the power supply PCB in at left rear, close to but not right up against the rear panel, and mark out its four mounting hole positions.

Mark out two more holes, just to the right of the power supply board; one roughly in line with the rear mounting holes and the other about 50mm closer to the front of the case. These will be used to hold a small Presspahn shield in place – for extra safety.

With the DAC in position, mark the locations directly below its four mounting holes (eg, using a sharp drill bit) although note that you may not be able to fit pillars to suit all four if you are putting the RCA sockets and switch underneath it; also consider where the wiring for these will go. Two or three mounting holes are sufficient.

Finally, choose a location for the *MiniReg* near the amplifier and DAC boards and mark out positions for its mounting holes too.

You can then remove all the modules from the case, drill all the holes to 3mm and de-burr them. There should be 17 mounting holes in total.

Testing the power supply

You can now temporarily install the power supply PCB in the case, with the mains connectors towards the rear and plug in the mains cord and switch. Make sure that the mains cord goes into the right socket, ie, that closest to the transformer. Ensure the fuse is in place and the cover clipped on.

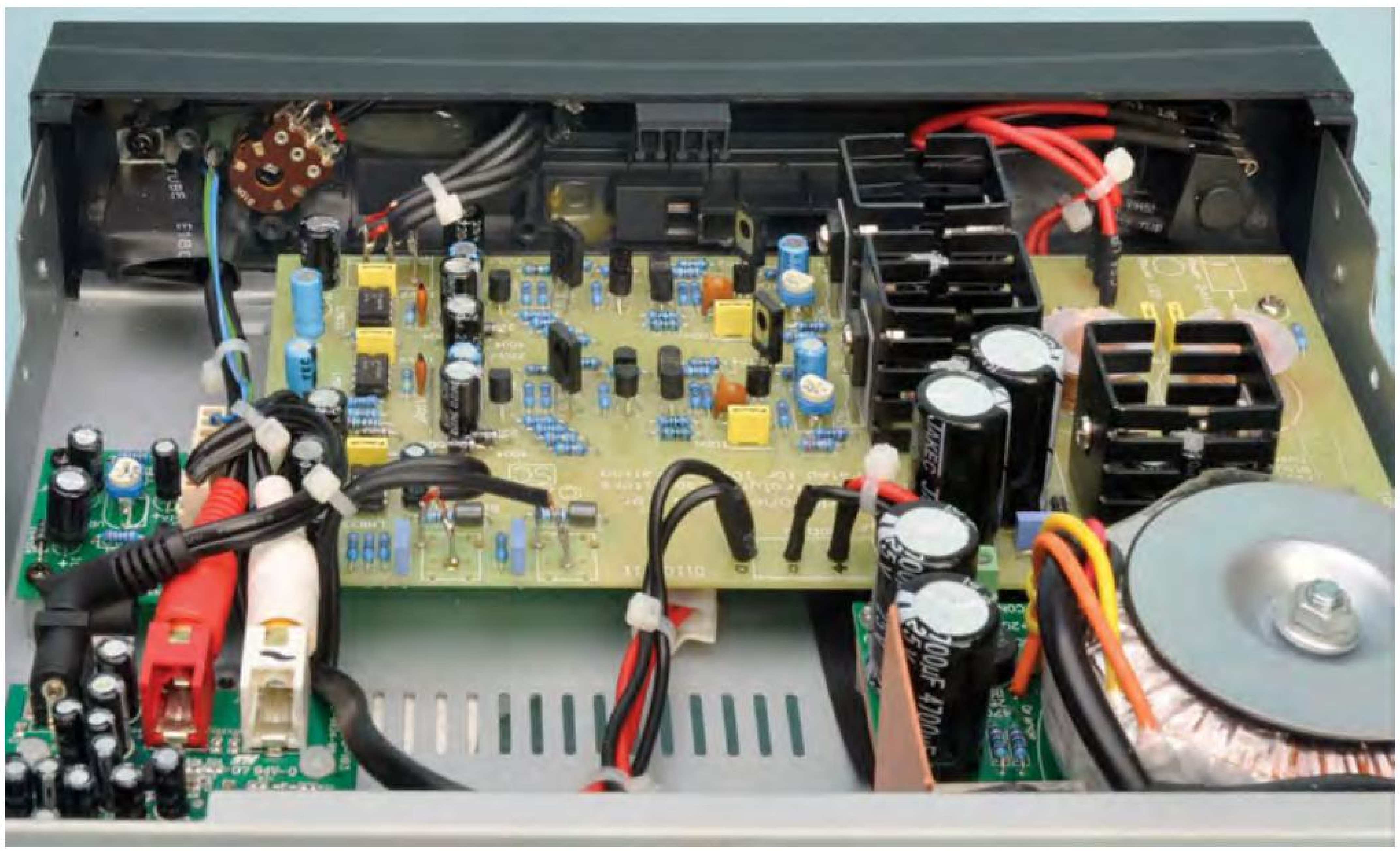
It's a good idea to connect a DMM (or two) to the low-voltage outputs with short lengths of wire (that can't short together) and clip leads so that you can check the output without having to hold probes in place. Note that you can use regular probes as long as you are careful *not to go anywhere near the mains* side of things while the unit is plugged in.

Check that there is no continuity between either mains plug pin and the case and that there are no loose conductors near the power supply board and switch the unit's mains switch to on. Then stand back, plug in the mains cord and switch on the power point. Check the voltages at the output screw terminal of the power supply. You should get pretty close to 20V between the middle terminal and those on either side, with the positive output being to the left. Ours measured around +21.5V and –21.5V.

If that tests OK, switch off and unplug the unit. If you didn't get anything, there could be an open circuit connection somewhere on the board, but if the fuse blows, that suggests there is a short circuit somewhere. In either case, you will have to remove the power supply board and inspect it carefully.

Wiring it up

With the modules built and all the holes in the case drilled or cut and de-burred, all that's left is to fit the modules and wire them up. We'll go through these remaining steps in *Part 3* next month and also present some performance data for the complete amplifier.

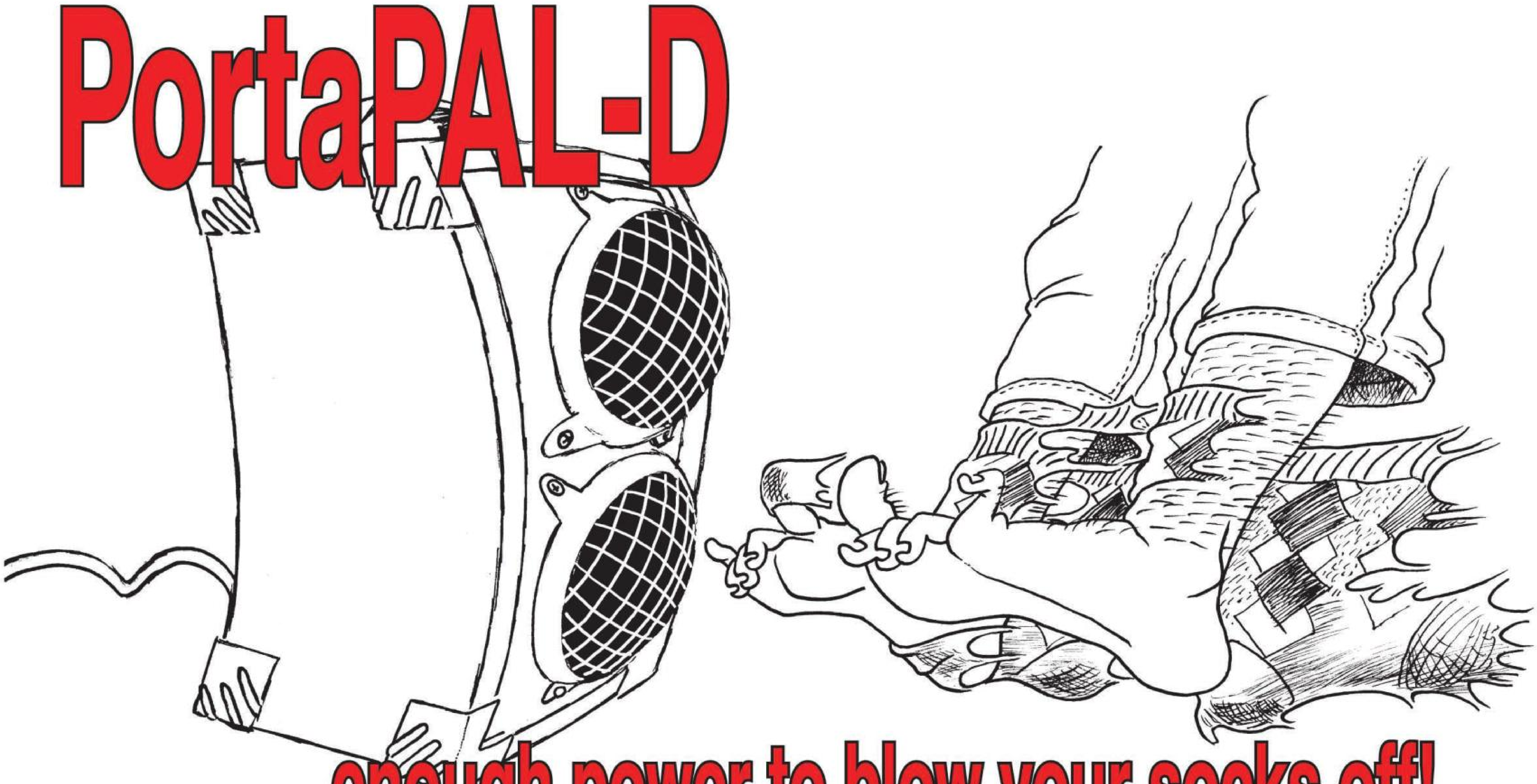


Here's a view from the back to the front, showing how we made the bits fit into what was originally a set-top-box case. Once the lid goes on you'd never know!

100W Digital Amplifier, Li-Po Battery . . .

by John Clarke

PortaPAL-D



... enough power to blow your socks off!

Part 3 – Building the Box

We've finished the electronics module – now it's time to put together the cabinet that houses that module, along with the two speakers to make LOTS of beautiful music.

The *PortaPAL-D* box is made from 16mm MDF (medium-density fibreboard) and rectangular DAR (dressed all round) pine. Its overall dimensions are 332 × 600 × 318 mm (w × h × d) , chosen to suit the standard MDF sheet sizes that are available.

The box is covered in speaker carpet with corner protectors, a handle and a 'top hat' for use with a speaker stand. The two speakers are each protected with a metal grille. Fig.15 show the speaker box construction.

The speakers are within their own sealed box, while an 'alcove' is made in the top rear of the box to house the *PortaPAL-D* chassis.

The inside volume for the speakers is around 33 litres; however, by packing the space with fibreglass insulation or fibrous wadding, the effective volume can be increased by as much as 40%. This *apparent* increase is due to a reduction in the speed of sound in the box due to the packing.

Fig.16 shows the typical bass end response with an unfilled box. This shows a 2.7dB peak at about 120Hz. With filling, this peak can be reduced to below 2dB, so that the bass response becomes more damped. A further benefit of wadding is reduction of internal reflections from the cabinet walls.

Incidentally, we used WinISD 0.44 box modelling software by Juha Hartikainen. (**www.linearteam.dk**). Thiele/Small parameters for the specified Altronics C2005 speakers are: V_{AS}= 27 litres, Q_{ES}= 0.962, Q_{MS}= 4.172, Q_{TS}= 0.782 and F_{O}= 58.428Hz.

The basic box shell comprising the top, bottom and two sides is made using two 600 × 300mm and two 300 × 300mm sheets of MDF. The front speaker baffle is 300 × 568mm and fits into these surrounds, as does the 300 × 365mm lower rear piece.

Two more pieces form the 'alcove', one 300 × 157mm and one 300 × 201mm.

These can be cut to size with a machine or hand saw and are assembled using PVA glue and nails or screws.

If they offer a cutting service, you might find it better to have the store where you purchase the MDF cut the pieces for you, as this will inevitably result in a squarer, more even finish.

Internal cleats using 12 × 12mm DAR pine can be placed inside the edges of the box. You will need to keep

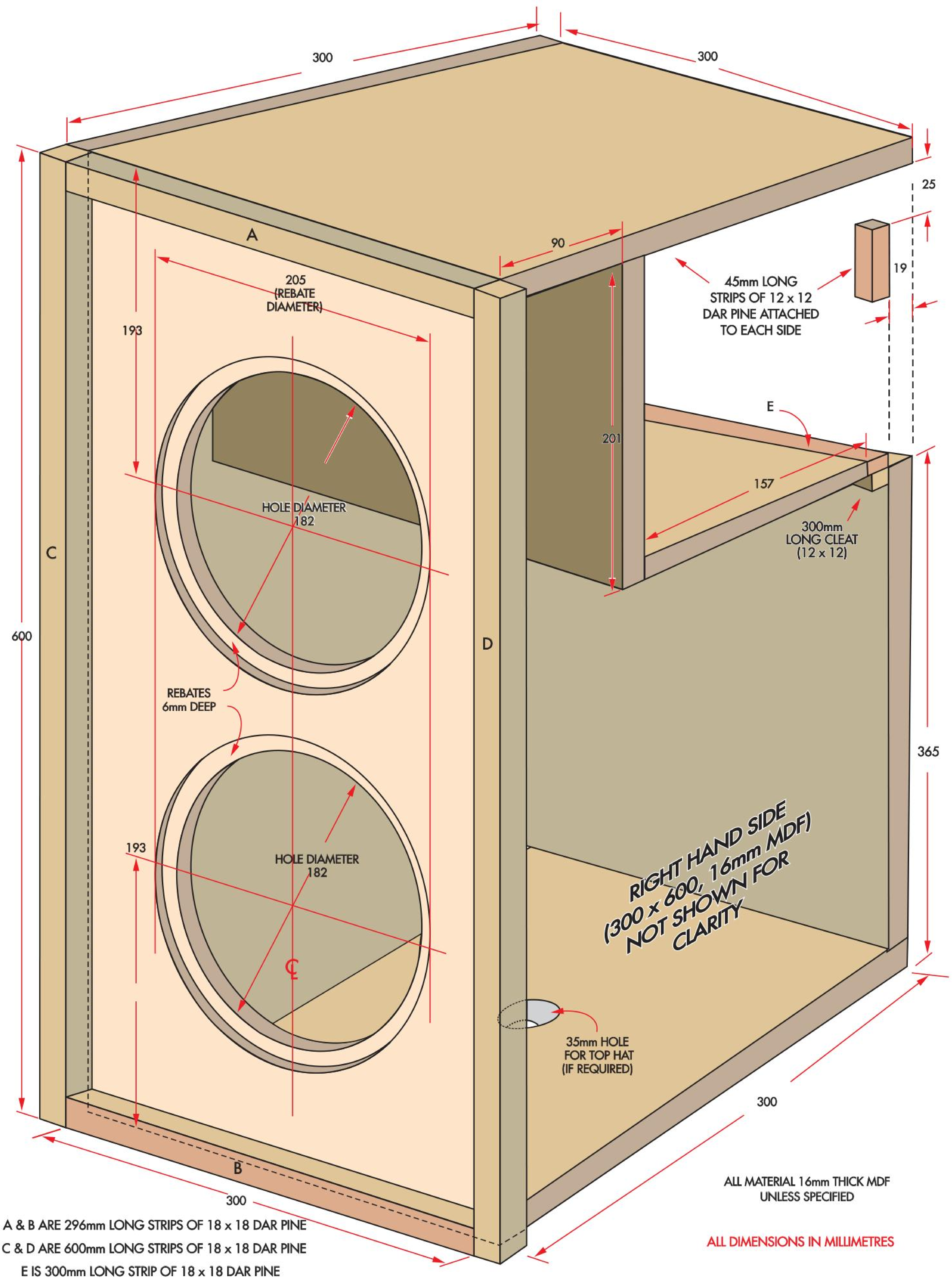

300
300
25
19
90
A
205
(REBATE
DIAMETER)
193
45mm LONG
STRIPS OF 12 x 12
DAR PINE ATTACHED
TO EACH SIDE
E
201
157
HOLE DIAMETER
182
300mm
LONG CLEAT
(12 x 12)
C
600
D
365
REBATES
6mm DEEP
193
HOLE DIAMETER
182
RIGHT HAND SIDE
(300 x 600, 16mm MDF)
NOT SHOWN FOR
CLARITY
℄
35mm HOLE
FOR TOP HAT
(IF REQUIRED)
300
B
300
ALL MATERIAL 16mm THICK MDF
UNLESS SPECIFIED
ALL DIMENSIONS IN MILLIMETRES
A & B ARE 296mm LONG STRIPS OF 18 x 18 DAR PINE
C & D ARE 600mm LONG STRIPS OF 18 x 18 DAR PINE
E IS 300mm LONG STRIP OF 18 x 18 DAR PINE

Fig. 15: the complete *PortaPAL-D* speaker cabinet, albeit without one side (that's so you can see how the electronics module housing is made). We've deliberately selected material dimensions so that it can be made from standard sheets of MDF (medium-density fibreboard). If you have the option, we'd suggest you get the MDF supplier to cut the panels to size for you – that way, you get nice, straight, clean cuts which make for a nice, straight, airtight box.

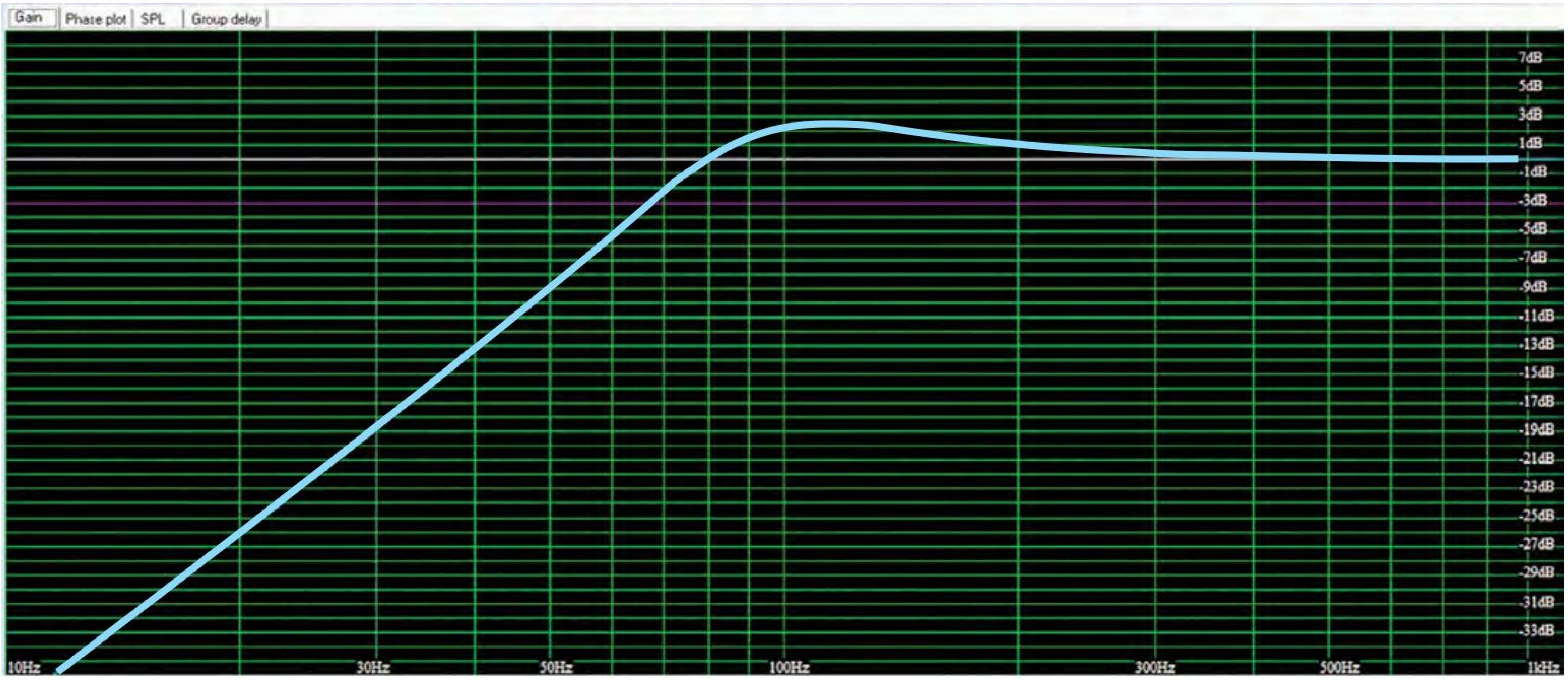


Fig.16: typical bass-end response with an unfilled 33 litre box. This shows a 2.7dB peak at about 120Hz. By packing the space with fibreglass insulation or bonded acetate (BAF) wadding, the effective volume can be increased by as much as 40%. This apparent increase is due to a reduction in the speed of sound in the box due to the packing. With this filling, the 2.7dB peak can be reduced to below 2dB so that the bass response becomes more damped. A further benefit of the wadding is a reduction of internal reflections from the cabinet walls.

the edges free of cleats where the box is made to house the *PortaPAL-D* chassis.

Once the glue has dried, mark out the 205mm and 182mm rebate diameters for the two loudspeakers to sit into on the front panel. Use a router to cut this rebate to a depth of 6mm. Now fully cut out the 182mm diameter holes with the router.

If you intend to install the speaker stand top hat, the hole for this (located centrally in the base of the box) can be cut now using a 35mm diameter hole saw.

Similarly, the holes for the handle that mounts on the top can be drilled.

While we only used (and specified in the parts list) a single handle on top of the box, the finished *PortaPAL-D* is quite heavy (17.5kg) so can be quite tiring if carried any distance.

You might prefer to place a handle, say, one-third down each side of the box, for easier carrying by two people. Another refinement worth considering is mounting four small furniture castors or wheels, one in each corner, to make the *PortaPAL-D* easier to move. That's up to you.

For the handle, we used two of the screws and captured nuts that are provided with the speaker grille clamps to mount the handle.

This leaves just three screws and nuts for each speaker grille mounting using the clamps. That is sufficient for these grilles when spaced out 120°, as shown in the photographs. Position the grilles over the speaker holes and mark out the hole positions for each clamp. Drill and attach each T-nut for the grilles and handle(s) by tightening up the screw to pull the nut into the MDF. Once these nuts are secured, remove the screws.

The front surround is 18 × 18mm DAR pine and can be cut and glued to the front of the box. The purpose of this is to recess the speakers (even though protected by grilles) from the inevitable bumps and scrapes of a portable system.

When the glue is dry, round off the eight corners of the box using a rasp or file to form the same curvature as the corner protectors.

Electronics chassis housing

The internal MDF boxed-in section for the *PortaPAL-D* chassis can now be made. Cut the sheets and DAR pine to size and glue these in place. Note that there is not much clearance between the back of the top speaker magnet and the internal box.

There needs to be a gap between the speaker magnet and box otherwise resonances are likely, so check that there is at least a 1mm gap between the speaker and the MDF sheet before finally gluing in place.

Note that when installing the speakers, there will be a nominal 1mm thickness of sealant around the rebate to seal the speaker from air gaps. This should be considered when checking the clearance gap.

Two 12 × 12 × 45mm DAR pine pieces are set 19mm in from the rear and 25mm down as shown. These are for supporting the top of the *PortaPAL-D* chassis. The lower 18 × 19 × 300mm DAR pine piece supports the lower *PortaPAL-D* chassis. When all is complete, ensure that all the joints are airtight by running a bead of PVA glue around all internal joints.

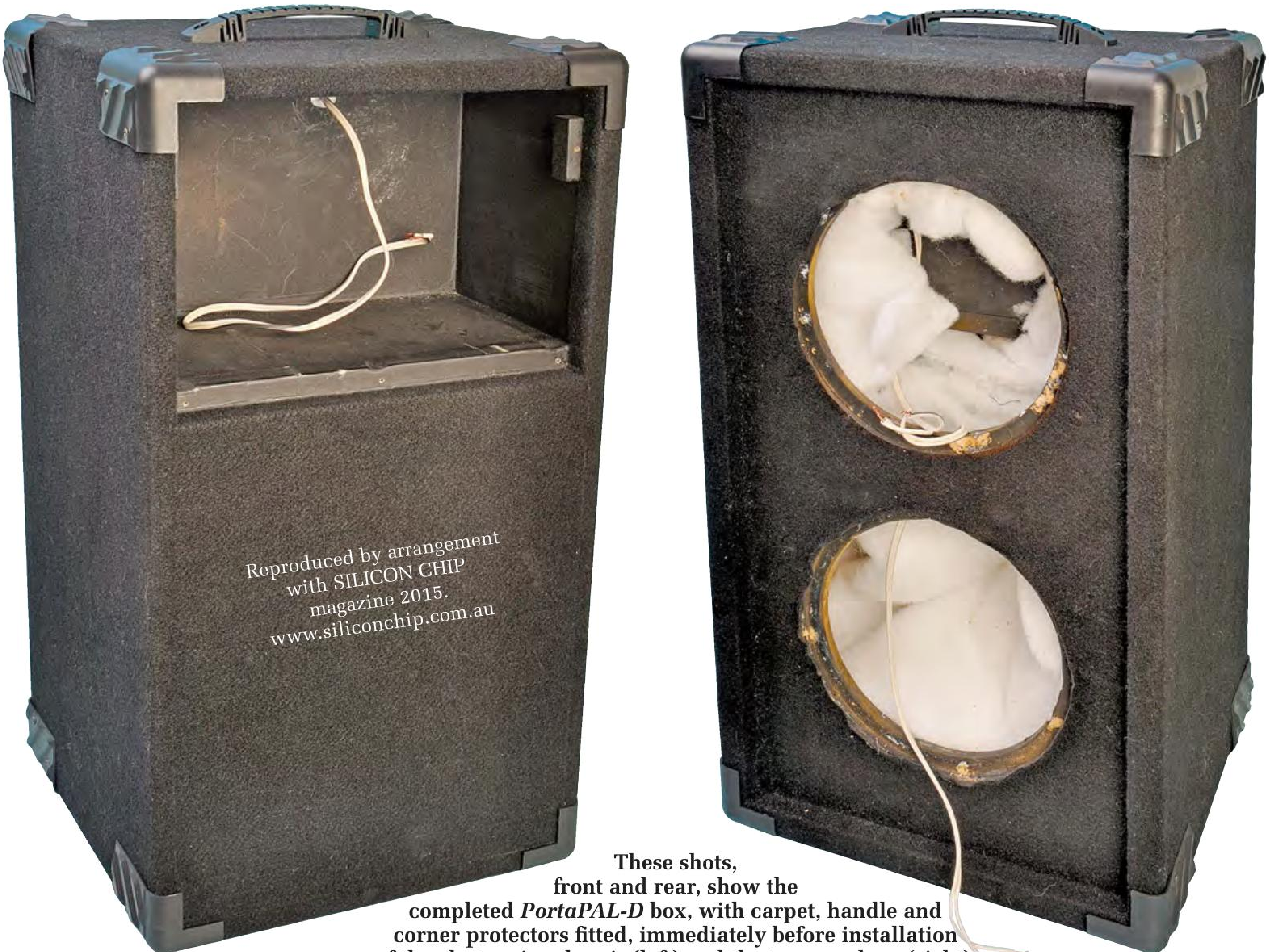
At this stage, test the *PortaPAL-D* chassis for fit into the sealed cavity. Hopefully, you will not need to make any changes to the box so that the chassis will fit. The advantage of having the two handles on the front panel will be realised when trying to remove the chassis.

Drill pilot holes for the 4g × 16mm panhead screws that secure the panel to the cabinet.

You may wish to paint the inside of the *PortaPAL-D* chassis section of the box black so that any exposed MDF or pine that is not covered by carpet is not obvious.

Carpet

The speaker carpet is attached to the box using contact adhesive. The carpet can be cut into just three separate pieces. First comes the surround piece that wraps around the entire sides of the box; second, the front baffle (296



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These shots, front and rear, show the completed *PortaPAL-D* box, with carpet, handle and corner protectors fitted, immediately before installation of the electronics chassis (left) and the two speakers (right). The speaker wire is already in place, emerging from the hole drilled in the left photo for connection to the *PortaPAL-D* chassis.

× 564mm); and third the rear panel at 300 × 401mm.

You will need a long straight edge to cut the carpet accurately and a steel ruler to make the measurements. A 'Stanley' knife (or a larger hobby knife) can be used to cut the carpet against a cutting mat.

Cut the front baffle carpet first. Lay it against the baffle as a sanity check and if it appears correct, remove and apply a smear of contact adhesive to the front baffle. Fix the carpet in place, smoothing out the carpet against the baffle (a small roller is ideal).

Now for the side carpet piece – this needs to be wide enough to also wrap around the front 18mm DAR pine, folding at two 90° bends to reach the front baffle. It also has to fold around at the back edge and reach 19mm inside the box where the *PortaPAL-D* chassis fits.

That means the carpet needs to be 389mm wide and 1864mm long. The amount of overhang at the front while wrapping the length around the box sides will need to be 36mm and the amount at the rear, 35mm.

Again, loosely wrap the carpet around the box to make sure it is going to fit properly and if all is well, remove and apply contact adhesive to the bottom of the box. Glue the beginning end of the carpet to this with the end of the carpet placed along the box edge.

Then apply the adhesive to the next side and wrap the carpet around that side taking care to maintain the correct overhang front and back. Continue gluing the top and then the other side, affixing the carpet as you go. Rub your roller (or hand) over the carpet to smooth it out and to maintain contact with the box till the adhesive is dry.

It's probably best to leave the box until the adhesive is dry to prevent pulling away. Once you're satisfied that the carpet won't move, trim each corner with a sharp knife or scissors to allow the carpet to wrap around the front and back of the box. Test how each piece will wrap around the box before cutting off too much carpet and before gluing in place. Any removal of too much carpet can be covered over with a suitable shaped extra carpet piece carefully glued in to fill the hole. The fold-over at the rear needs to go down the sides into the recessed *PortaPAL-D* cavity by 19mm.

The rear piece for the lower portion of the box can be cut to 300mm wide × 401mm, and this needs to start by wrapping into the bottom edge of the *PortaPAL-D* cavity by 19mm and then glued down the 18mm DAR pine and then the back of the 300 × 365mm panel. The side wrap carpet can be cut to just 16mm for the lower part of the box, allowing the 300mm width to fit.

Fittings

When the adhesive is dry, cut out the carpet about 3mm smaller than the

Here's what your finished *PortaPAL-D* should look like, from the front (speaker side) shown at left and the rear (control side) shown at right. With maximum power of 100W and continuous rating of 50W, you're not going to lack for volume – and the comprehensive range of mixer controls means it will handle just about any application. Add the Li-Po battery and inbuilt charger, it's a real winner! With 20/20 hindsight, we would have replaced the single carry handle with a pair of more robust handles on the side – it does get a little heavy even after carrying it a short distance! (That does mean a two-person carry, though). And we'd also think about putting some small castors or wheels on the bottom to make it easier to cart around.

SILICON CHIP
PORTAPAL-D
Portable Public Address Loudspeaker

205mm perimeter of the rebate hole for each speaker hole. Also find the T-nuts for the speaker grill clamps and handle and poke a hole through the carpet at each nut. A size 2 Philips screwdriver can do this.

If using the top hat, carefully cut out a hole in the carpet, same diameter as the top hat stem, and insert that into the hole. By pressing the top hat down in place, and using the top hat flange as a cutting template, carefully cut the carpet around the perimeter of the top hat flange. Remove the circle of carpet and reinsert the top hat. Pilot-drill the mounting holes for this and screw in the screws. Attach the handle to the top of the box.

The corner protectors can now be attached using 6g × 16mm bronze-coloured countersunk wood screws.

Installing speakers

The speakers are next and will require wiring up as they are installed.

The specified speakers (Altronics C-2005) are 200mm, 8Ω coaxial models and connected in parallel, to present a 4Ω load to the amplifier.

These speakers feature push-button terminals so no soldering is needed. However, they must be connected in phase; ie, plus to plus and minus to minus. The easiest way to do this is to cut the 1m length of 7.5A figure-8 cable in half, bare all ends to 1cm and tightly twist together one end of each (make sure the stripes or polarity markers are twisted together).

Drill a small hole suitable for one of the figure-8 wires to pass through the rear of the *PortaPAL-D* box cavity, about 25mm down from the inside top.

Hang the twisted-together pair of cables out of the top speaker hole and the other end of one cable out of the bottom speaker hole.

From inside the case, push the other single figure-8 through the hole in the box cavity.

We'll mount the lower speaker first. Connect the figure-8 cable to the push terminals, with the stripe or marker on the figure-8 going to the red (+) terminal.

To give an air-tight seal between speaker and box, we're using Blu-Tack putty. Roll a long length so that you end up with a cylinder about 2mm in diameter and mould this all the way around the rebated section in the box for the lower speaker.

Repeat until you have a solid run of Blu-Tack all the way around (ie, no gaps).

Pack about 90% of the wadding in the volume behind the lower speaker hole and slide the speaker into the lower hole under the carpet lip that surrounds the rebated outer hole diameter. Press the speaker into the hole to compress the Blu-Tack. Now carefully (!) drill pilot holes into the rebate at the four mounting holes on the speaker and secure the speaker in place with 8g × 12mm panhead screws.

Now we'll fit the upper speaker. It has the twisted-together pairs of figure-8 connecting it but there is plenty of room in the push terminals. Once again, ensure the striped wires go to the red or '+' terminal.

Insert the remaining wadding around the outside of the speaker hole (but not directly behind where the speaker goes) and install the speaker as before using Blu-Tack and screws. Now the grilles can be positioned over the speakers and held in place with the clamps.

Where the speaker wire comes through from the speakers to the *PortaPAL-D* chassis, ensure that you have plenty of cable to work with and then seal the hole with Blu-Tack. This wire connects to the 'to speakers' terminals on the speaker protector.

A 2-way 15A terminal strip is an option to allow the 'to speakers' output to be extended for an easier connection to the speaker wire.

Insert the *PortaPAL-D* chassis into the box cavity and secure using 4g × 16mm panhead screws.

Construction of the *PortaPAL-D* is now finished. Turn on and check that it works with the inbuilt battery, then connect power and check that it charges.

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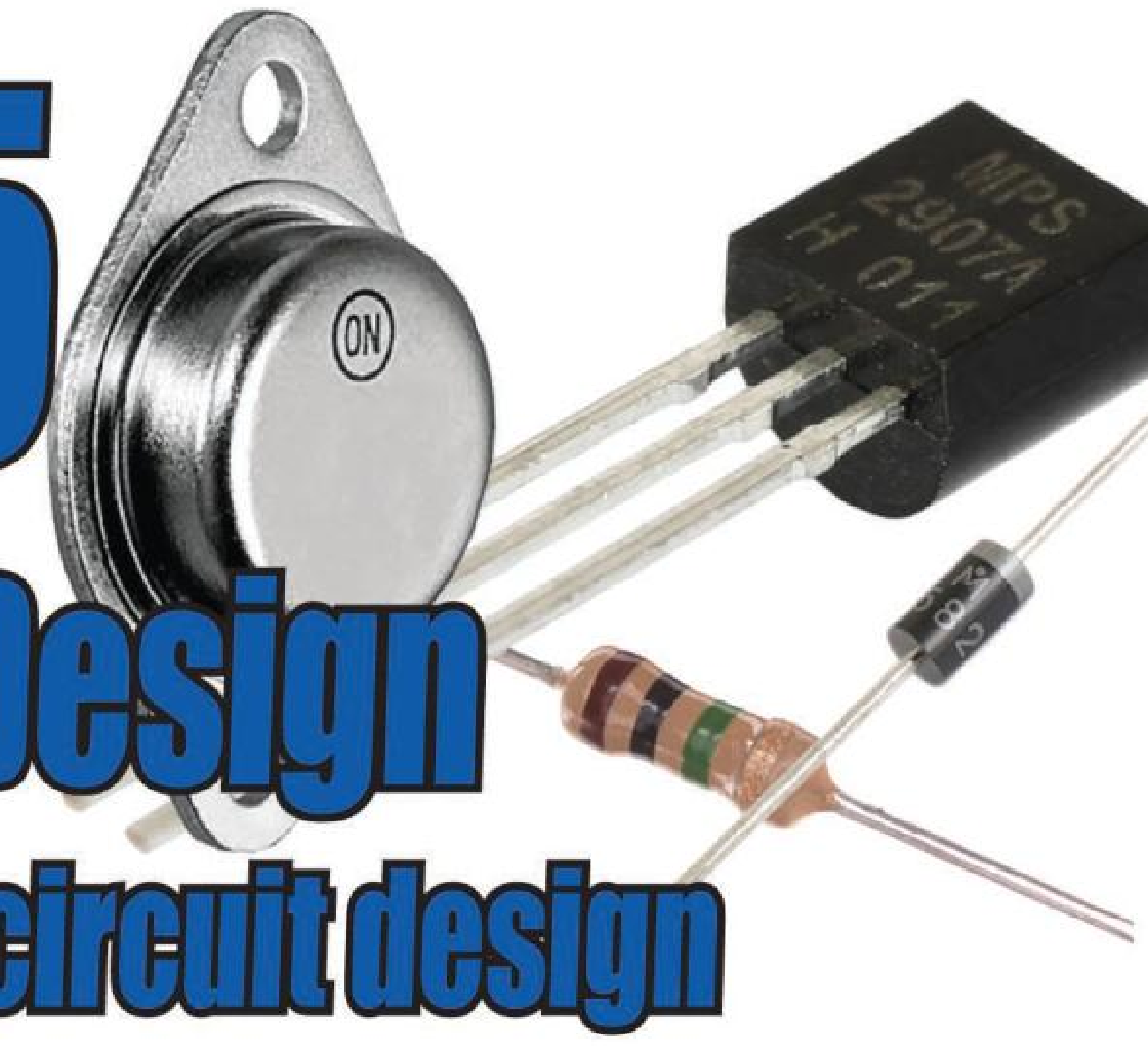


Discrete Linear Circuit Design

Part 1: Introducing discrete linear circuit design

by Mike and Richard Tooley

Welcome to *Teach-In 2015* – this series is aimed at anyone wishing to develop a detailed understanding of linear discrete semiconductor devices and how they are used in a diverse range of circuits. We hope you will join us on this exciting voyage of discovery. Apart from understanding some basic principles, no previous knowledge of analogue electronics will be assumed and, whereas our practical projects have been specifically designed to meet the expectations of the serious audiophile and Hi-Fi enthusiast, they are suitable for novice builders. The culmination of *Teach-In 2015* is a series of modules that will build into a high-quality audio amplifier and although it will be built using only inexpensive discrete components, it will out-perform comparable designs based on integrated circuits.

Introduction

Each part will be devoted to a different aspect of discrete linear circuit design such as modelling and simulation, measurement and testing, noise and distortion. In each future instalment you will find sections entitled *Discover, Knowledge Base*, and *Get Real*. From time to time we will also include a series of special *How to do* features: how to use SPICE-based computer simulation, how to produce a neat printed circuit board, and how to design an effective heat sink. In *Discover* we will introduce important topics relating to discrete linear design, while *Knowledge Base* will provide the more general, underpinning knowledge that you need in order to make full use of each instalment.

In *Get Real* we will be describing a series of modular circuits that have been designed to put theory into practice and act as a platform that you can use to demonstrate, experiment with, and evaluate the techniques introduced in the series. Each of these projects will allow you to explore different aspects of discrete linear circuit design, including the use of real and virtual test instruments. We will also explain how the modules can be configured for individual use in a variety of your own applications or combined together to form the basis of a high-quality audio system.

Software

Modern electronic circuit design relies heavily on computer software and we will be aiming to show you just how powerful and useful this can be. We have used the Student version of TINA Design Suite to design and extensively test each of our practical projects, and we will be showing you how to use powerful SPICE-based software to enter, edit and test your own discrete linear circuits prior to actually building them. A TINA file for each of the projects will be available for download from *EPE's* website. We have also been using the popular Circuit Wizard software to create printed circuits for each of our practical project modules. The Circuit Wizard files will also be made available for downloading from *EPE's* website. Alternatively, the printed circuit boards for each practical project can be purchased from *EPE's PCB Service*. Please note that both of these powerful software packages come with component libraries that include the sub-set of components and linear devices used in our *Teach-In 2015* series.

When the time comes to test your circuits we will show you how to use virtual test instruments in order to carry out a variety of useful measurements of important parameters, including gain, frequency response, noise and distortion. The software that we will be using is Soundcard Oscilloscope from Christian Zeitnitz (which does not require a licence for private, non-commercial and public educational use) and the immensely powerful but reasonably priced Virtins Multi-instrument. All you will need to use these programs is a couple of test leads and a reasonably modern Windows-based PC or laptop fitted with a good specification sound card.

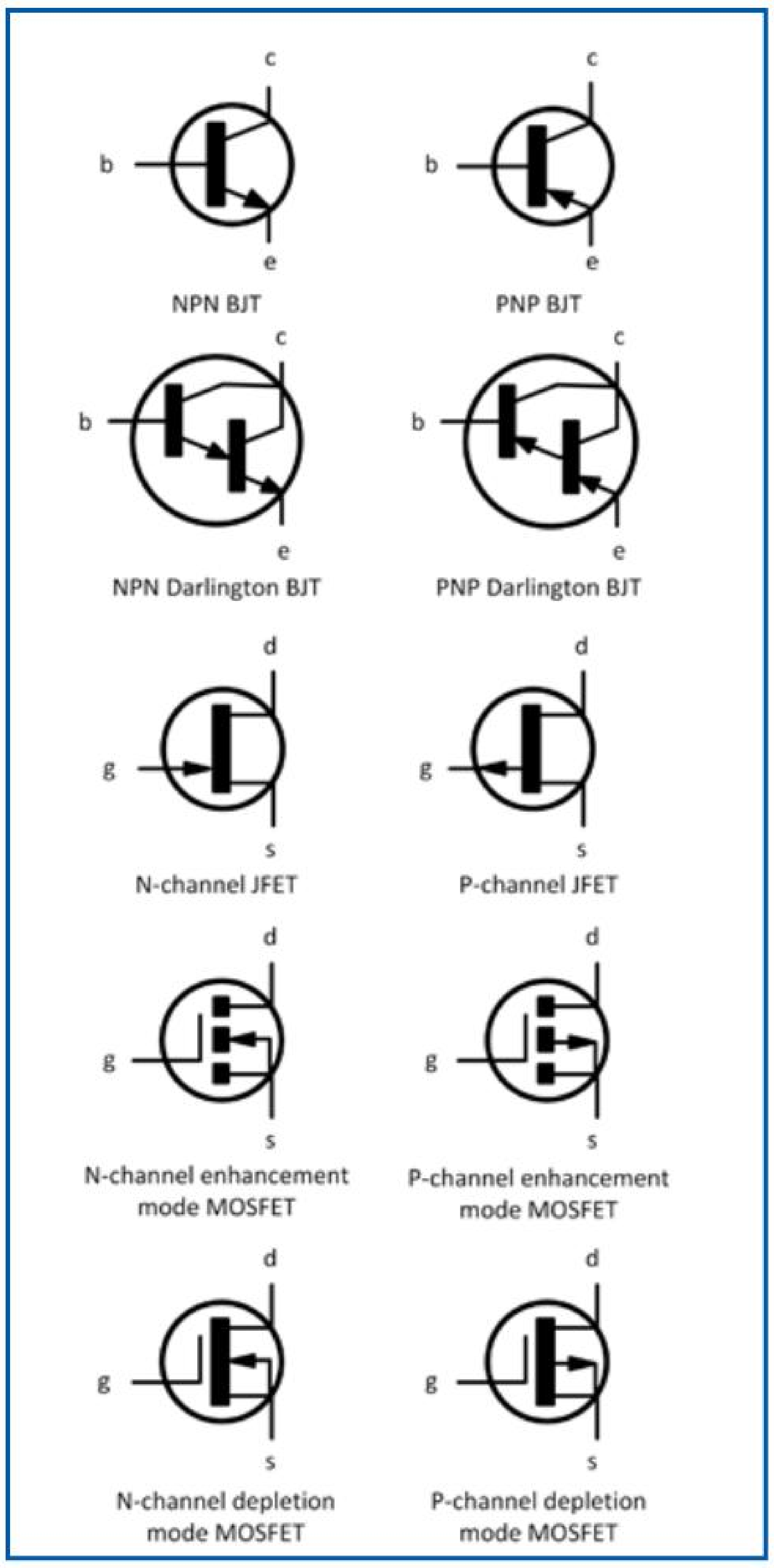
Why discrete linear?

At this point, and if you've previously only used integrated circuits, you might be tempted to ask why we might want to abandon chips in favour of discrete devices. Unlike circuit designs based on integrated circuits, the use of discrete components offers the designer the greatest possible freedom in arriving at a working circuit. In other words, the designer has total control of the circuit and does not have to rely on the peculiarities of a pre-built integrated circuit device. It is then possible to configure a circuit exactly as required and without the constraints imposed upon it by the designers of the available range of integrated circuits. With discrete devices, superior performance can often be achieved at lower cost. This means not having to pay for 'features' that you might not need or want. It also provides designers with a much wider scope for experimentation and optimisation.

For example, the immensely popular LM386 audio amplifier chip is an excellent choice for use in a wide range of simple audio applications. However, when operating from a 16V supply and delivering a mere 1W of audio into a 32Ω load the device produces a massive 10% of total harmonic distortion (THD). Furthermore, any attempts to reduce the load impedance in order to get more power will produce even more distortion. The problem of achieving a sensible amount of output power at an acceptably low value of THD could be easily resolved by abandoning the integrated circuit design in favour of a discrete design based on a few low-cost transistors. We will show later, how our design for a high-quality linear power amplifier will significantly outperform a design based on a popular integrated circuit, with greater flexibility and at lower cost.

What you need to know

We are going to make very few assumptions about what you already know. We will, however, assume that you know what resistors, capacitors and inductors are and how they operate. You should also know how to make basic measurements on a circuit, such as how to use a meter to check test point voltages and currents. We will also assume that you have access to a desktop or laptop computer on which you


c
b
e
NPN BJT
c
b
e
PNP BJT
c
b
e
NPN Darlington BJT
c
b
e
PNP Darlington BJT
d
g
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N-channel JFET
d
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s
P-channel JFET
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g
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N-channel enhancement mode MOSFET
d
g
s
P-channel enhancement mode MOSFET
d
g
s
N-channel depletion mode MOSFET
d
g
s
P-channel depletion mode MOSFET

Fig.1.1 Symbols for a variety of different transistor types

can run the software applications that we will be using in conjunction with circuit design and testing. You need to be able to apply Ohm's Law and have a basic grasp of DC and AC circuit theory (for example, understanding how resistors behave when they are connected into series and parallel networks). That said, we are going to keep the theory to a minimum and make use of computer modelling and simulation whenever possible. That way, we hope to dispel the generally held belief that linear discrete design is a black art!

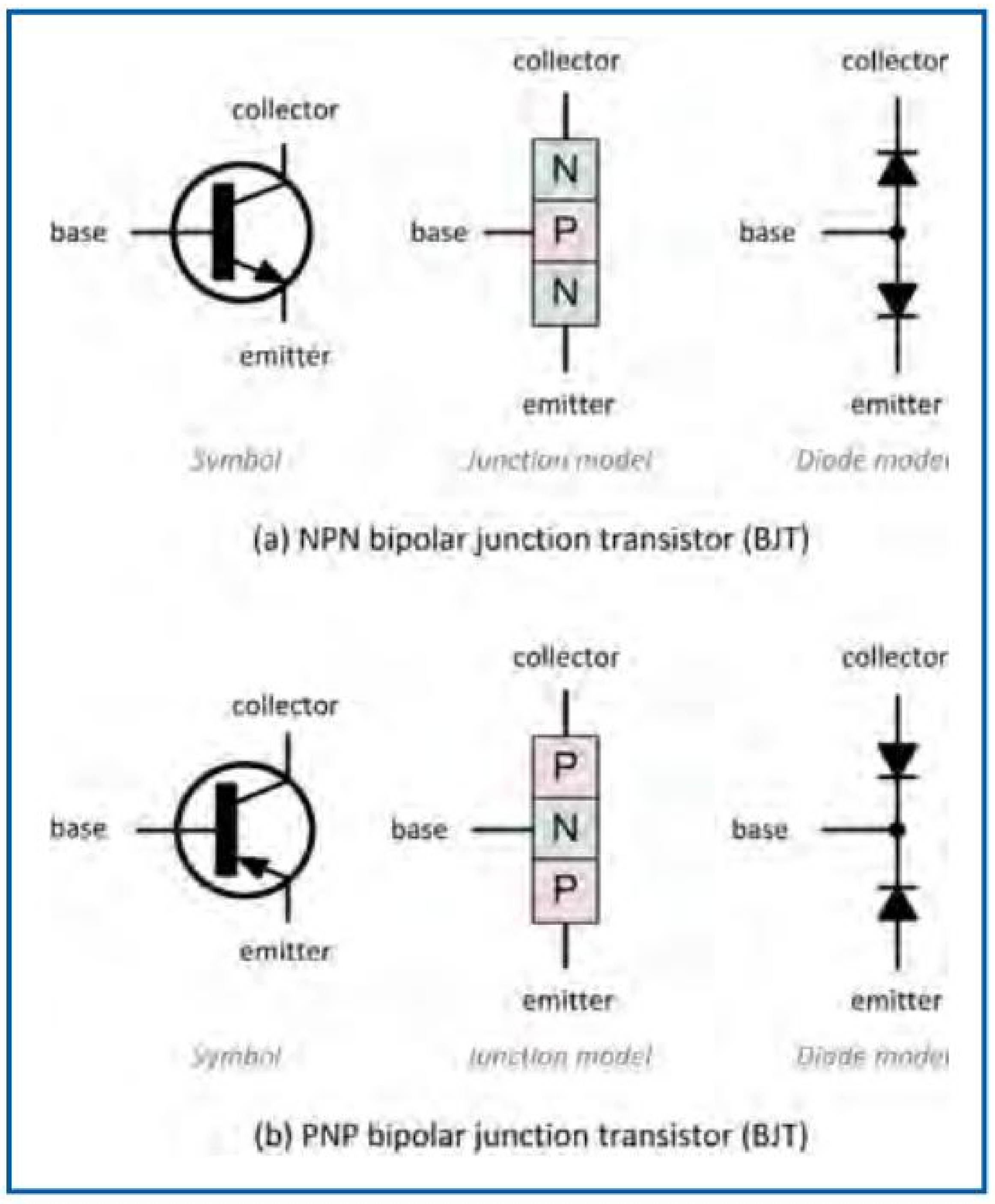


Fig.1.2 Symbols, junction and diode models for NPN and PNP BJTs

In Part 1, *Discover* introduces discrete semiconductors and focusses on the transistor in particular. *Knowledge Base* describes the theory relating to the amplifiers in which transistors are used. Our practical feature, *Get Real*, takes the form of a simple pre-amplifier and our *Special Feature* will introduce you to SPICE and how to get started with TINA Design Suite.

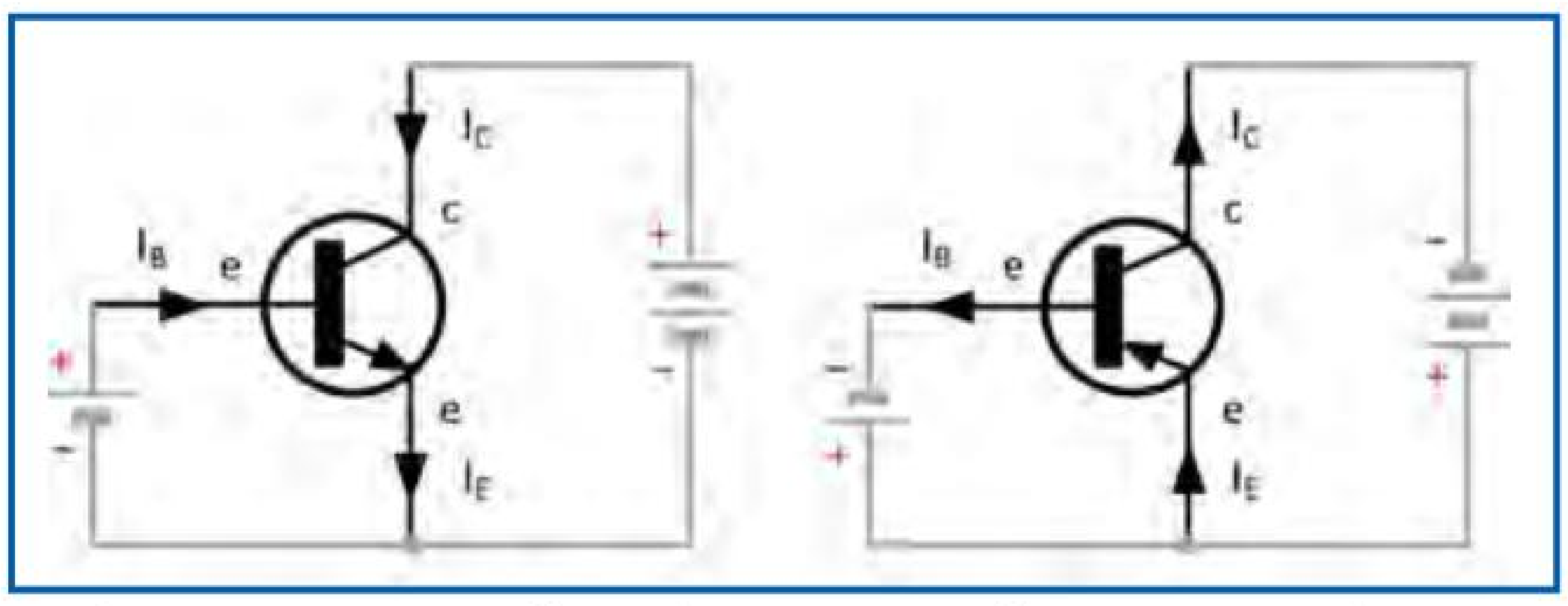


Fig.1.3 Current flow in NPN and PNP transistors

Discover: Transistors

The workhorse of discrete circuits, the transistor, is essentially the same device that's found in very large quantities inside an integrated circuit. The term transistor stands for 'transfer resistor' which provides a clue as to how the device operates. A wide variety of discrete transistors is currently available to the circuit designer, and the circuit symbols for the most common types are shown in Fig.1.1. For newcomers, knowing which device to choose for use in a particular application can often be baffling so, to keep things simple we have based the *Teach-In 2015* series on a sub-set of some of the most popular bipolar junction transistors (BJT). All of these devices are readily available at low cost and regular readers will doubtless already be familiar with some of them. However, for the benefit of newcomers to electronics we will just spend a little time explaining what a BJT is and how it operates.

Bipolar junction transistors (BJT)

BJTs comprise N-P-N or P-N-P semiconductor junctions of silicon (Si) material made by carefully adding impurities creating the 'N' and 'P' regions (see Fig.1.2). The junctions are extremely small and they are produced in a single slice of silicon by diffusing the impurities through a photographically reduced mask. The connections to the semiconductor material are called 'collector', 'base' and 'emitter'.

An important point to note is that each junction within the transistor – collector-base or base-emitter – is a P-N junction and each of these junctions when taken on their own is equivalent to a diode. However, since the central base region is made narrow, when the base-emitter junction is forward biased and the collector-base junction is reverse biased there is interaction between the base and collector circuits as current carriers are swept across the junction. Current carriers leaving the emitter are swept across the narrow base region into the collector and only a relatively small number appear at the base. To put this into context, the current flowing in the emitter circuit is typically 100 or more times greater than that flowing in the base.

The direction of conventional current flow in a BJT is from emitter to collector in the case of a PNP transistor, and collector to emitter in the case of an NPN device (see Fig.1.3). In both cases, the amount of current flowing from collector to emitter is determined by the amount of current flowing into the base. Note that we have indicated the polarity of the applied voltages in Fig.1.3. In the case of an NPN device, the collector and base are both at a positive potential with respect to the emitter, whereas in the case of a PNP device, the applied potentials are reversed and the collector and base are both at a negative potential with respect to the emitter. Note that we've used the battery symbols shown in Fig.1.3 to indicate the polarity of the applied voltage – they are not real batteries!

From Fig.1.3 we arrive at an important equation that relates the current flowing in the collector, base, and emitter circuits:

$$I_E = I_B + I_C$$

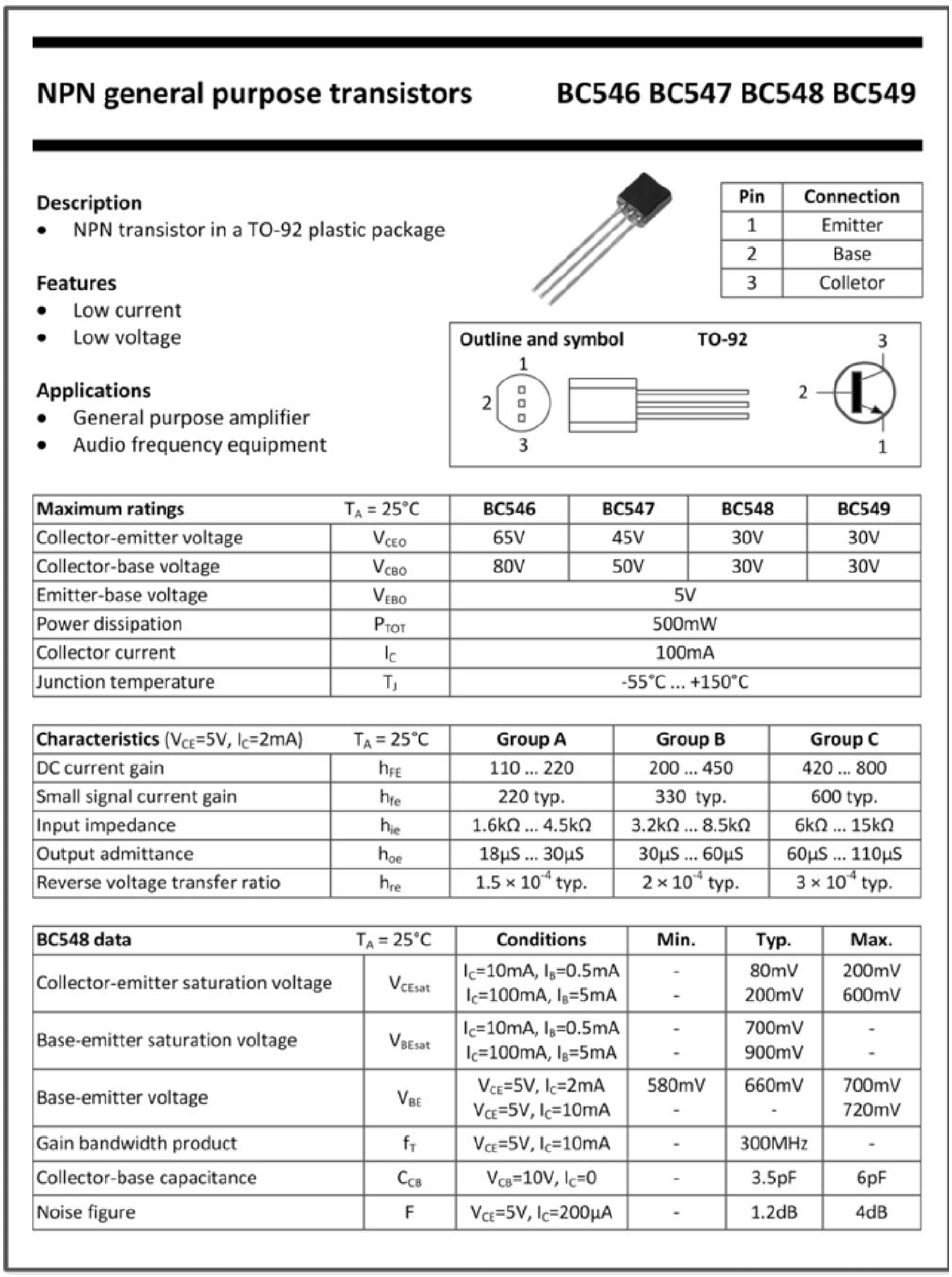
I_E is the emitter current, I_B is the base current, and I_C is the collector current (all expressed in the same unit – the amp).

Datasheets

The manufacturers of semiconductor devices publish information on their devices in the form of one or more datasheets. These provide useful information on a particular semiconductor type and they usually include a brief description, a summary of the important features, typical applications and maximum ratings. Datasheets can also include characteristics provided in both tabulated and graphical form. At first sight this information might be a little baffling, so it's worth looking at an example of how a typical datasheet is organised and the information that can be derived from it. Fig.1.4 shows the first page of a datasheet for a range of popular general-purpose NPN transistors: the BC546, BC547, BC548 and BC549.

The datasheet tells us that this is a 'family' of NPN general-purpose transistors with similar characteristics and that they are supplied in a TO-92 plastic package (the outline, symbol and pin connections are shown inset in the datasheet). The first table in the sheet (headed 'Maximum ratings') provides a summary of various parameter values that must not be exceeded. For example, the BC546 is rated for a maximum collector-emitter voltage of 65V. The BC548 and BC549 devices are, by contrast, rated only for a maximum collector-emitter voltage of 30V.

Of particular note here is the maximum value of emitter-base voltage. For all four



NPN general purpose transistors **BC546 BC547 BC548 BC549**

Description

- NPN transistor in a TO-92 plastic package

Features

- Low current
- Low voltage

Applications

- General purpose amplifier
- Audio frequency equipment

Pin	Connection
1	Emitter
2	Base
3	Colletor

Outline and symbol **TO-92**

Maximum ratings	T_A = 25°C	**BC546**	**BC547**	**BC548**	**BC549**
Collector-emitter voltage	V_{CEO}	65V	45V	30V	30V
Collector-base voltage	V_{CBO}	80V	50V	30V	30V
Emitter-base voltage	V_{EBO}	5V			
Power dissipation	P_{TOT}	500mW			
Collector current	I_C	100mA			
Junction temperature	T_J	-55°C ... +150°C			

Characteristics (V_{CE}=5V, I_C=2mA)	T_A = 25°C	**Group A**	**Group B**	**Group C**
DC current gain	h_{FE}	110 ... 220	200 ... 450	420 ... 800
Small signal current gain	h_{fe}	220 typ.	330 typ.	600 typ.
Input impedance	h_{ie}	1.6kΩ ... 4.5kΩ	3.2kΩ ... 8.5kΩ	6kΩ ... 15kΩ
Output admittance	h_{oe}	18µS ... 30µS	30µS ... 60µS	60µS ... 110µS
Reverse voltage transfer ratio	h_{re}	1.5×10^{-4} typ.	2×10^{-4} typ.	3×10^{-4} typ.

BC548 data	T_A = 25°C	**Conditions**	**Min.**	**Typ.**	**Max.**
Collector-emitter saturation voltage	V_{CEsat}	I_C=10mA, I_B=0.5mA I_C=100mA, I_B=5mA	- -	80mV 200mV	200mV 600mV
Base-emitter saturation voltage	V_{BEsat}	I_C=10mA, I_B=0.5mA I_C=100mA, I_B=5mA	- -	700mV 900mV	- -
Base-emitter voltage	V_{BE}	V_{CE}=5V, I_C=2mA V_{CE}=5V, I_C=10mA	580mV -	660mV -	700mV 720mV
Gain bandwidth product	f_T	V_{CE}=5V, I_C=10mA	-	300MHz	-
Collector-base capacitance	C_{CB}	V_{CB}=10V, I_C=0	-	3.5pF	6pF
Noise figure	F	V_{CE}=5V, I_C=200µA	-	1.2dB	4dB

Fig.1.4 Datasheet extract for the popular BC546, BC547, BC548 and BC549 BJTs

devices this is quoted as 5V and it is effectively the maximum reverse voltage that can be applied to the base-emitter junction. As we explain later, this junction is normally forward biased (and therefore conducting) but in a reverse-biased condition the junction becomes extremely vulnerable to an over-voltage condition.

The maximum total power dissipation is important in a number of applications, particularly for devices where appreciable power is being delivered. In the case of this family of devices, the total power dissipation (the sum of the power dissipated in the two junctions) should be no more than 500mW. So, in an application where the collector-emitter voltage is 15V and the collector current is 400mA the device will be operating outside its maximum permissible ratings even though the collector-emitter voltage and collector current do not individually exceed the manufacturer's specification. Note that maximum collector power is sometimes stated rather than total power dissipation. The former is the product of the collector current and collector-emitter voltage, while the latter also includes the power present in the base-emitter junction. There is no great difference in these two ratings so, in practice, either one will give you a clue as to the maximum permissible power that can be dissipated within a particular device.

Table 1.1 Selected data for some popular bipolar junction transistors

Device	Type	I_C max.	V_{CE} max.	P_{tot} max.	h_{FE} at I_C	Package	Typical application
2N3906	PNP	200mA	40V	625mW	150 at 2mA	TO92	General purpose
2N4919	PNP	1A	80V	30W	10 at 1A	TO225	General purpose driver
2N4923	NPN	3A	80V	30W	50 at 500mA	TO126	General purpose power
BC337	NPN	800mA	50V	625mW	300 at 100mA	TO02	Driver and low power output
BC548	NPN	100mA	30V	500mW	250 at 2mA	TO92	General purpose amplifier
BC558	PNP	100mA	30V	500mW	250 at 2mA	TO92	General purpose amplifier
BC560	PNP	100mA	45V	500mW	250 at 2mA	TO92	Low noise amplifier
TIP32	PNP	3A	80V	40W	50 at 1A	TO220	Power amplifier

The next table – Characteristics – summarises the main operational parameters for the family. The transistors are available from the manufacturer sorted into three individual 'gain groups'. Group A provides current gains (h_{fe}) of between 110 and 220, Group B between 200 and 450, and Group C from 420 to 800. Note that there is a very wide variation in the gain offered by similar devices (hence the need to organise them into different gain groups) and also there is a small overlap between the three ranges. If, for example, you need a transistor with a current gain of no more than 200 you would only need a Group A device. On the other hand, if you need a gain of more than 400 then it would be best to opt for a Group C device.

The characteristics listed in the table are given in the form of 'hybrid parameters'. These will be explained in next month's *Teach-In 2015*. Notice that there is a fair amount of variation across the three gain groups. For example, the data shows that the input resistance (h_{ie}) for a device in Group C could easily be more than four times greater than that of a device taken from Group A.

The last table provides typical operating data for the family of transistors with minimum, typical and maximum figures. It tells us, for example, that the base-emitter voltage should typically be 660mV for a device operating with V_{CE} = 5V and I_C = 2mA. We have used this, and other information from the datasheet in the design of this month's practical project. For comparison purposes, Table 1.1 shows selected date for a variety of popular BJTs.

Knowledge Base: Amplifiers

Making signals larger, or 'amplification', is a very common requirement in electronic circuits. The signals from a microphone, for example, might only be a few millivolts. When connected to the input stage of an amplifier that same microphone might only be able to deliver a current of a few microamps. At the other extreme, in order to drive a loudspeaker to sufficient volume to fill a large room we might need several volts and a current of several amps. So, in a public address system we might need to amplify both the signal voltage and the signal current several thousand times. Thus gain, in

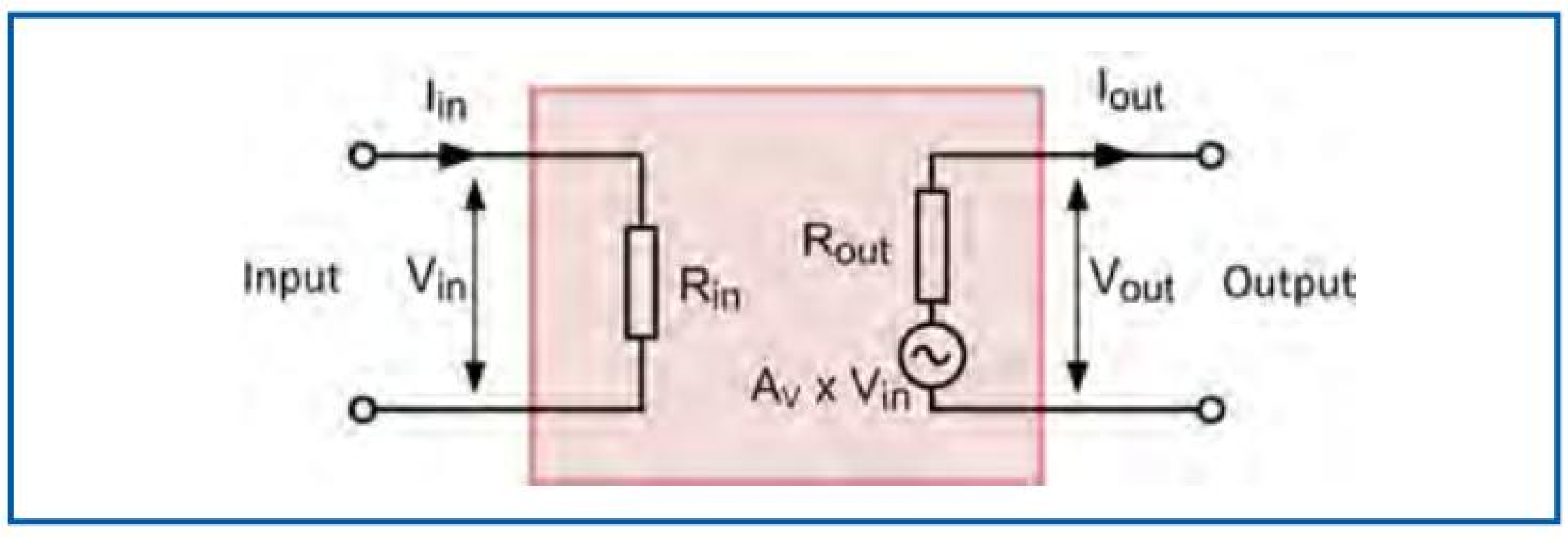


Fig.1.5 Input and output resistance

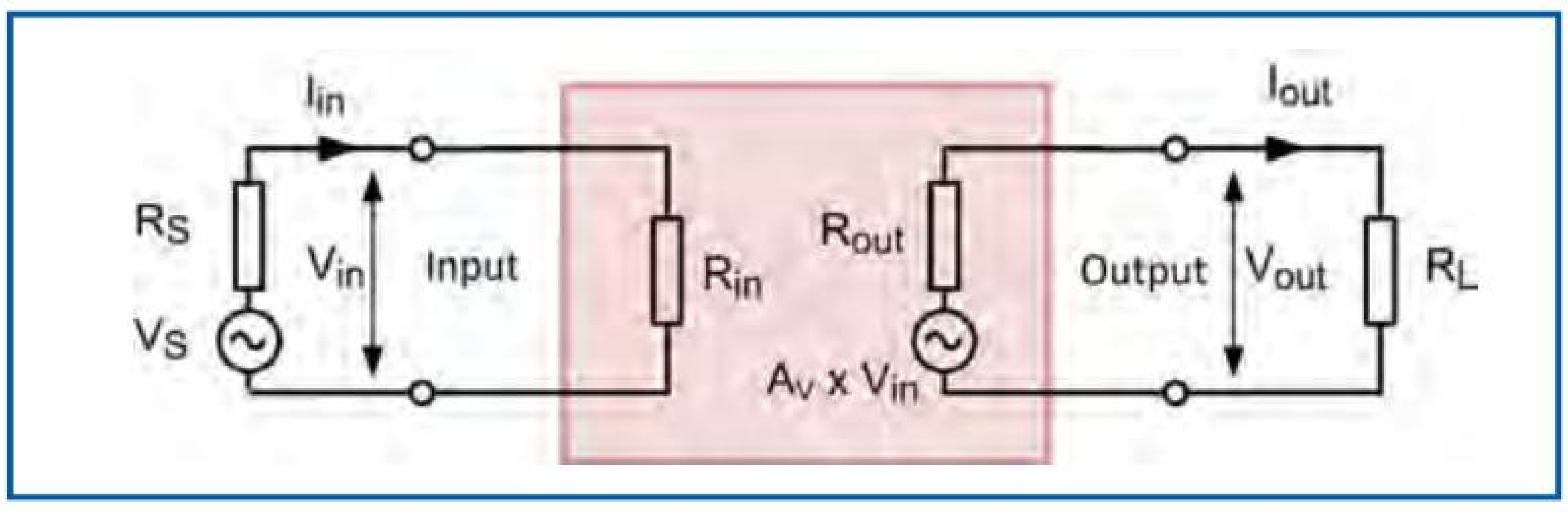


Fig.1.6 Output and load resistance

terms of voltage ('voltage gain') and/or current ('current gain'), is a fundamental requirement of an amplifier.

Types of amplifier

Many different types of amplifier are found in electronic circuits. They include small-signal AC-coupled amplifiers; DC or direct-coupled amplifiers (where direct voltage is amplified as well as AC); large-signal and power amplifiers that cater for appreciable voltage and/or current levels; low-noise amplifiers that produce very little noise that might otherwise degrade a signal; audio frequency (AF) amplifiers that operate over the band of frequencies normally associated with audio signals (20Hz to 20kHz); wideband amplifiers that operate over a wide range of frequencies (typically from a few hertz to several megahertz); and radio frequency (RF) amplifiers that operate in the band of frequencies associated with radio signals (100kHz to several gigahertz).

Gain

As briefly mentioned earlier, gain can be expressed in terms of both voltage and current and, since both are important, we can also express gain in terms of power. Voltage gain is simply the ratio of the voltage produced at the output of an amplifier to the voltage present at its input. Likewise, current gain is the ratio of the current produced at the output of an amplifier to the current at its input. Finally, power gain is the ratio of power that an amplifier delivers to a load connected to its output to the power supplied to its input. Thus we have:

$$A_v = \frac{V_{out}}{V_{in}} \qquad A_i = \frac{I_{out}}{I_{in}} \qquad A_p = \frac{P_{out}}{P_{in}}$$

where A_v, A_i and A_p represent voltage, current and power gain respectively.

Note that, since power is the product of voltage and current we can also express power gain as:

$$A_p = \frac{I_{out} \times V_{out}}{I_{in} \times V_{in}}$$

Now, to put this into context, let's assume that our public address microphone produces a signal voltage of 5mV and a signal current of 10μA (an input power of 50nW). To produce the required level of volume using a loudspeaker we might require an output signal of 10V and a current of 1A (an output power of 10W). In this case we would need a voltage gain of:

$$A_v = \frac{V_{out}}{V_{in}} = \frac{10\text{V}}{5\text{mV}} = 2000$$

Together with the voltage gain we would need a current gain of:

$$A_i = \frac{I_{out}}{I_{in}} = \frac{1\text{A}}{10\mu\text{A}} = 100{,}000$$

The required power gain would then be:

$$A_p = \frac{I_{out} \times V_{out}}{I_{in} \times V_{in}} = \frac{1\text{A} \times 10\text{V}}{10\mu\text{A} \times 5\text{mV}}$$

$$= \frac{10\text{W}}{50\text{nW}} = 200{,}000{,}000$$

Linearity

Apart from the obvious requirement of making a signal voltage or current larger, an important requirement of most amplifiers is that the output signal should be a faithful copy of the input signal, albeit larger in amplitude. We describe these as 'linear amplifiers' and the need to retain linearity is an important consideration in their design.

Some other types of amplifier are 'non-linear', in which case their input and output waveforms will not necessarily be similar. In practice, the degree of linearity provided by an amplifier can be affected by a number of factors, including the amount of bias applied (see later) and the amplitude of the input signal. It is also worth noting that a linear amplifier will become non-linear when the applied input signal exceeds a threshold value. Beyond this value the amplifier is said to be overdriven and the output will become increasingly distorted if the input signal is further increased.

Amplifiers are usually designed to be operated with a particular value of bias supplied to the active devices (ie, transistors). For linear operation, the active devices must be operated in the linear part of their transfer characteristic. This form of operation is known as 'Class A', and in it the circuit conditions (or 'bias point') must be adjusted so that the device is operated at or near the mid-point of the linear part of its transfer characteristic. Note also that current will flow in the transistors of a Class A amplifier for a complete cycle of the signal waveform. At no time during the cycle will the current fall to zero as it might do with some of the other classes of operation. This is an important point that we will return to in a later instalment of *Teach-In 2015*.

Input and output resistance

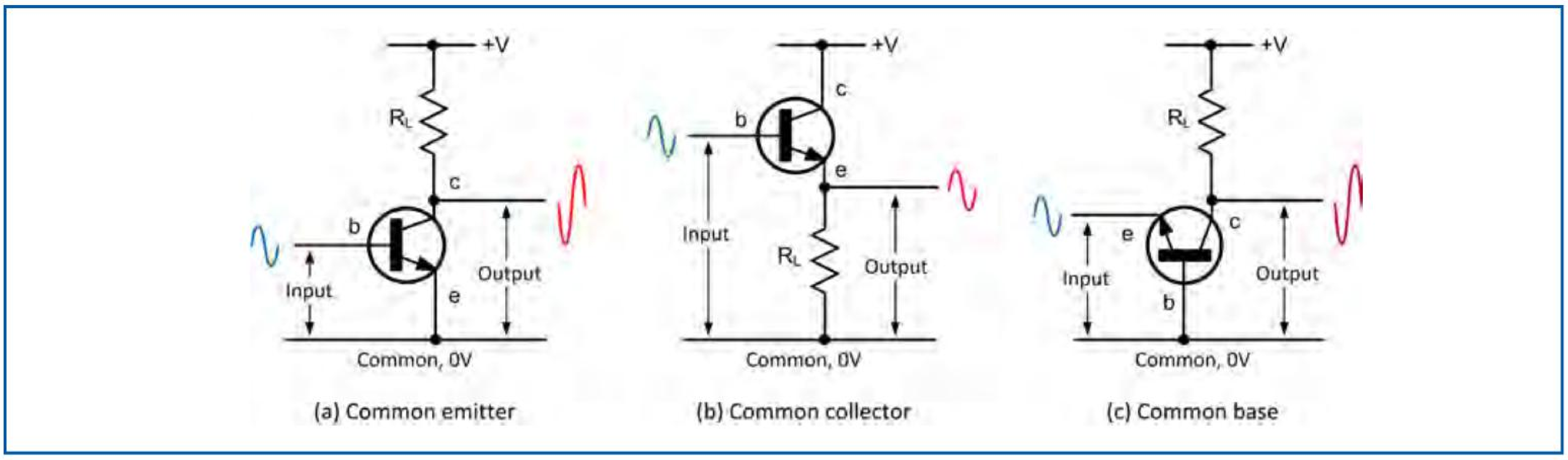
The input resistance of an amplifier is that which would be 'seen' between the two input terminals. The output resistance of an amplifier is that which would be seen looking back into the output of the amplifier. This statement needs a little more explanation. Fig.1.5 shows an amplifier as a 'black box' with two input terminals and two output terminals. Since this is an 'equivalent' representation of an amplifier, we have lumped together the voltage that the amplifier produces (as a result of a signal voltage present at its input) into a voltage generator (the circle with the squiggle inside it). The voltage generator produces current in whatever the two output terminals are connected to. This results in an output voltage drop which appears across the two output terminals.

At this stage it is important not to confuse the output resistance of an amplifier with the resistance of the load (circuit) to which it is connected. The output resistance is 'inside' the amplifier, while the load is external and is something that we have introduced.

In series with the voltage generator we have shown the output resistance of the amplifier. When the amplifier is connected to a load this has the effect of not only reducing the output voltage but also reducing the output current, as we shall see next.

Fig.1.6 shows the equivalent circuit that we've just met, but with the input and output connected. At the input we've shown the signal source represented by a voltage generator, V_S, connected in series with its internal resistance, R_S. These two components represent whatever circuit or device is used at the input of the amplifier. For example, a typical dynamic (moving coil) microphone might be represented by a perfect voltage source of 10mV connected in series with a resistance of 600Ω. At the output, we've shown a resistance, R_L, that represents the load imposed on the amplifier. In the case of a loudspeaker this might be a resistance of 8Ω. Note that this resistance should more correctly be referred to as an 'impedance', as we will explain later.

A particular condition arises when the output resistance (R_{out}) is the same as the resistance of the load (R_L). This is the 'matched' condition and it corresponds to the case in which maximum power is transferred from the amplifier to the load. Note that a matched condition is not always desirable. In the case of a power amplifier, for example, we normally require the output resistance to be very much less than that of the load in order to maximise the voltage that appears across the load. In the case of a typical audio power amplifier, the output resistance might be a fraction of an ohm, while the loudspeaker that it drives might have an impedance of somewhere between 4Ω and 8Ω.



(a) Common emitter (b) Common collector (c) Common base

Fig.1.7 Common-emitter BJT amplifier configurations

Table 1.2 BJT amplifier characteristics

Characteristic	Common emitter – Fig.1.7(a)	Common collector – Fig.1.7(b)	Common base – Fig.1.7(c)
Voltage gain	Medium/high (40)	Unity (1)	High (250)
Current gain	High (200)	High (200)	Unity (1)
Power gain	Very high (8000)	High (200)	High (200)
Input resistance	Medium (5kΩ)	High (100kΩ)	Low (150Ω)
Output resistance	Medium/high (25kΩ)	Low (100Ω)	High (100kΩ)
Phase shift	180° (inverted)	0° (non-inverted)	0° (non-inverted)
Typical applications	General purpose AF, RF and wideband amplifiers	Impedance matching, input and output stages	RF and VHF/UHF amplifiers

In Fig.1.6, if the source resistance, R_S, is small compared with the input resistance, R_{in}, the input voltage that the amplifier receives will be almost the same as the signal voltage, V_S. If, on the other hand, R_S is large compared with the input resistance, R_{in}, the input voltage that the amplifier sees will be reduced by the ratio, R_{in} to (R_S + R_{in}). To avoid the consequent reduction in input voltage, R_{in} is often made very much larger than R_S. A typical value for R_{in} might be 50kΩ, while R_S might be less than 5kΩ.

A particular condition arises when the input resistance, R_{in}, is the same as the resistance of the source, R_S, and the output resistance, R_{out}, is the same as the load, R_L. This is the 'matched' condition and it corresponds to the case in which maximum power is transferred from the source to the input and from the output to the load. This condition might be necessary in certain applications, for example where one or more amplifiers and attenuators are connected in cascade.

If the load resistance R_L in Fig.1.6 is large compared with output resistance R_{out}, the output voltage that the load receives will be almost the same as $A_V \times V_{in}$. If, on the other hand, R_L is small compared with the output resistance R_{out}, the voltage that the load receives will be reduced by the ratio, R_L to (R_L + R_{out}). Once again, to avoid a reduction in output voltage, R_{out} is often made very much smaller than R_L. A typical value for R_L might be 10kΩ, while R_S might be less than 1kΩ.

Resistance versus impedance

We often use the terms 'resistance' and 'impedance' interchangeably, but there is a vital difference between these two terms and it is important to understand that difference. Strictly speaking, resistance refers to DC conditions – ie, the ratio of direct voltage to direct current present in a circuit. Impedance, on the other hand, relates to what goes on when a more general AC signal is applied to a circuit. It is the ratio of signal voltage to signal current and, strictly speaking this is what we should be referring to when we are talking about amplifiers.

A circuit has 'impedance' when it exhibits both resistance and reactance. However, since the reactance is often negligible within the normal range of signal frequencies, we can usually safely ignore it. In this case, at the input and output of an amplifier (and as far as the signal is concerned) the value of impedance is virtually the same as the value of resistance 'seen' by the signal. This is why the two terms can often be used interchangeably. So, to keep things as simple as possible we will simply refer to resistance (rather than impedance) and show it as such in our circuit diagrams.

Amplifiers and common rails

Amplifiers have four terminals (two for the input and two for the output) but since transistors have three terminals one of the transistor's terminals must be connected in 'common' with one of the input terminals and one of the output terminals. This connection is variously referred to as common or signal ground, and it is often the same connection as that used for the 0V supply. In fact, both of the supply voltage connections to an amplifier are common, at least as far as the signal (AC) is concerned. At first sight, this might sound odd, particularly as there is a DC voltage drop between the supply voltage rails, but it is important to remember that the supply exhibits a very low impedance at signal frequencies and therefore appears as a short circuit as far as the signal is concerned.

BJT transistor amplifiers

Discover introduced you to the BJT, so let's put the device to good use by connecting it as an amplifier. Since the BJT has three terminals (electrical connections) three basic circuit configurations are possible. These three circuit configurations depend upon which one of the three transistor connections is made common to both the input and the output. In the case of bipolar transistors, the configurations are known as: 'common emitter', 'common collector'(or 'emitter follower') and 'common base' (see Fig.1.7). The three basic circuit configurations exhibit quite different performance characteristics, as shown in Table 1.2.

Current gain

Conventional bipolar junction transistors (BJT) operate on current rather than voltage, and so current gain is used as a measure of its effectiveness as a BJT when used as an amplifying device. In common-emitter mode, the input current is applied to the base and the output current appears in the collector, so the common-emitter current gain is given by:

$$h_{FE} = \frac{I_C}{I_B}$$

where h_{FE} represents the DC current gain, I_C is the collector current, and I_B is the base current. When small (rather than large) signal operation is considered, the values of I_C and I_B are incremental (small changes rather than steady or DC values). The current gain is then given by:

$$h_{fe} = \frac{\text{small change in } I_C}{\text{corresponding small change in } I_B}$$

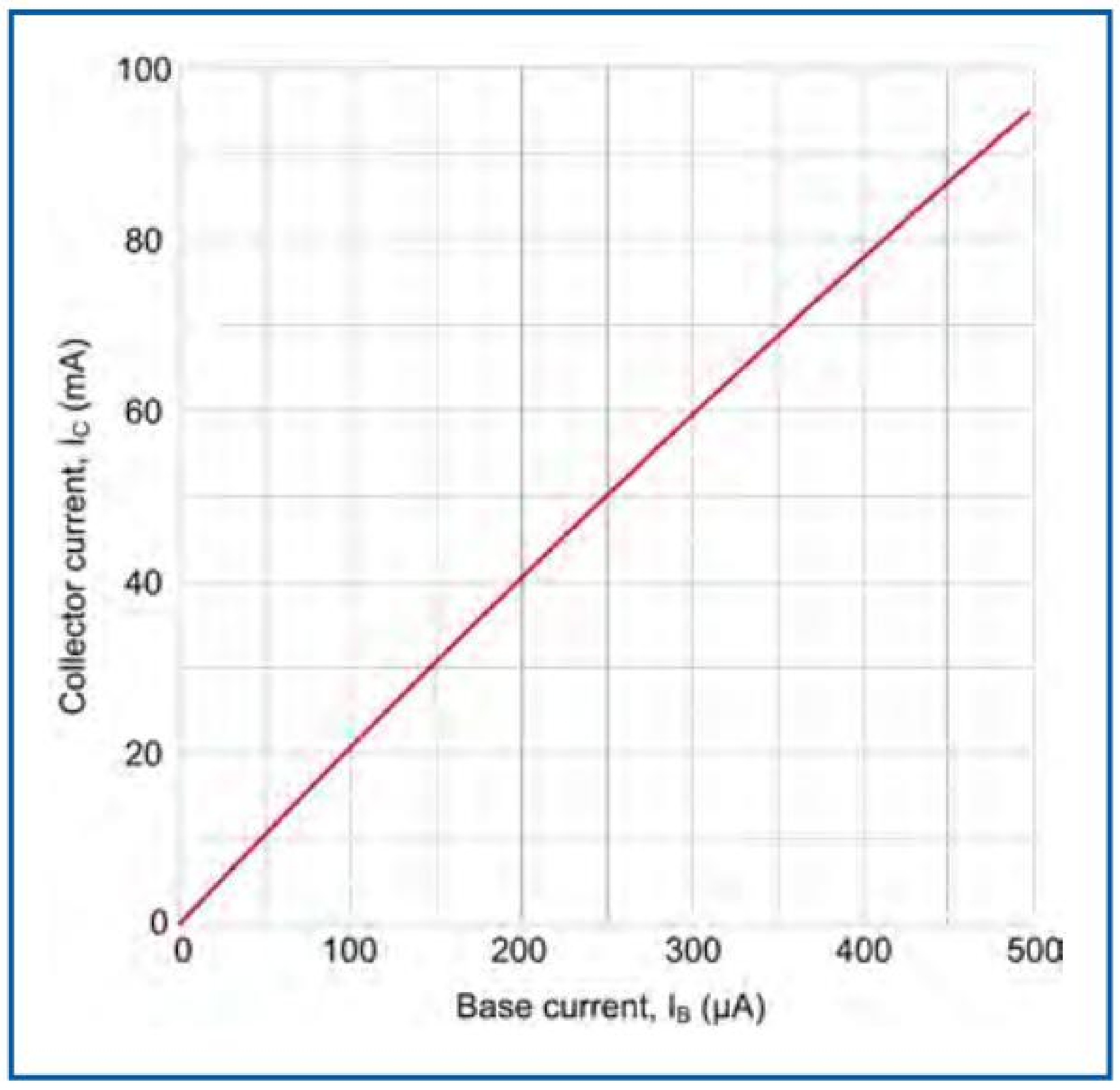


Fig.1.8 Typical transfer characteristic (I_C plotted against I_B) for a BJT

where h_{fe} represents small signal (AC) forward current gain.

Values of h_{FE} and h_{fe} can be obtained from the transfer characteristic (I_C plotted against I_B) shown in Fig.1.8. Note that h_{FE} is found from corresponding static values while h_{fe} is found by measuring the slope of the graph. Also note that, if the transfer characteristic is linear, there is little (if any) difference between h_{FE} and h_{fe}. In the typical case shown in Fig.1.8, the transistor exhibits a current gain of about 200.

It is worth noting that small-signal current gain (h_{fe}) varies with collector current. For most small-signal transistors, h_{fe} is a maximum at a collector current in the range 1mA and 10mA. Furthermore, current gain falls to very low values for power transistors when operating at very high values of collector current. Another point worth remembering is that most transistor parameters (particularly common-emitter current gain, h_{fe}) are liable to wide variation from one device to the next. In order to guarantee operation to specification with a variety of different devices, it is important to design circuits on the basis of the minimum expected value for h_{fe}.

Before moving on, it's worth taking a quick look back at Table 1.1 to see how corresponding values of DC current gain and collector current vary for different devices. Notice how the power devices exhibit significantly less current gain at high values of collector current when compared with general purpose devices which have much higher values of current gain, but specified at much smaller collector currents. In next month's instalment of *Teach-In 2015* we will show you how equivalent circuits and hybrid parameters are used to accurately model the performance of BJT amplifiers.

We've already mentioned voltage gain, current gain, and power gain, but there are several other parameters that are important when specifying the performance of an amplifier. They include phase shift, frequency response, and bandwidth.

Phase shift

Phase shift is the phase angle between the input and output signal voltages measured in degrees. The measurement is usually carried out in the mid band where, for most amplifiers, the phase shift remains relatively constant. Note also that conventional single-stage transistor amplifiers provide phase shifts of either 180° (common emitter) or 0° (common collector and common base).

Frequency response

The frequency response of an amplifier is usually specified in terms of the upper and lower cut-off frequencies of the amplifier. These frequencies are those at which the output power has dropped to 50% (otherwise known as the –3dB points) or where the voltage gain has dropped to 70.7% of its mid-band value (see Fig.1.9). Note that frequency response graphs are usually plotted on a logarithmic scale.

Bandwidth

The bandwidth of an amplifier is usually taken as the difference between the upper and lower cut-off frequencies (ie, $f_2 - f_1$ in Fig.1.9). The bandwidth of an amplifier must be sufficient to accommodate the range of frequencies present within the signals that it is presented with. Many signals contain harmonic components (ie, signals at $2f$, $3f$, 4f, etc. where f is the frequency of the fundamental signal). To reproduce a square wave, for example, requires an amplifier with a very wide bandwidth (note that a square wave comprises an infinite series of harmonics). Clearly it is not possible to perfectly reproduce such a wave, but it does explain why it can be desirable for an amplifier's bandwidth to greatly exceed the highest signal frequency that it is required to handle!

In the example frequency response shown in Fig.1.9, the amplifier has a virtually flat frequency response extending from 10Hz to 10kHz and a mid-band (maximum) voltage gain of 5. The lower cut-off frequency is 37Hz and the upper cut-off frequency is 37kHz. The bandwidth (equal to the difference between these two frequencies) is therefore approximately 37kHz.

Practical amplifier circuits

We stated earlier that the optimum value of bias for a Class A (linear) amplifier is that value which ensures that the active devices are operated at the midpoint of their transfer characteristic. In practice, this means that a static value of collector current will flow even when there is no signal present. Furthermore, the collector current will flow throughout the complete cycle of an input signal – conduction will take place over an angle of 360°. At no stage will the transistor be saturated nor should it be cut-off (the state in which no collector current flows).

In order to ensure that a static value of collector current flows in a transistor, a small current must therefore be applied to the base of the transistor. This current can be derived from a separate base bias supply or it can be supplied from the same voltage rail that supplies the collector circuit. Fig.1.10 shows a basic Class A common-emitter amplifier circuit in which the base bias resistor, R_B, provides base current and collector load resistor, R_L, provides collector current.

The signal is applied to the base terminal of the transistor via a coupling capacitor, C_{in}. This capacitor removes the DC component of any signal applied to the input terminals and ensures that the base bias current delivered by R_B is unaffected

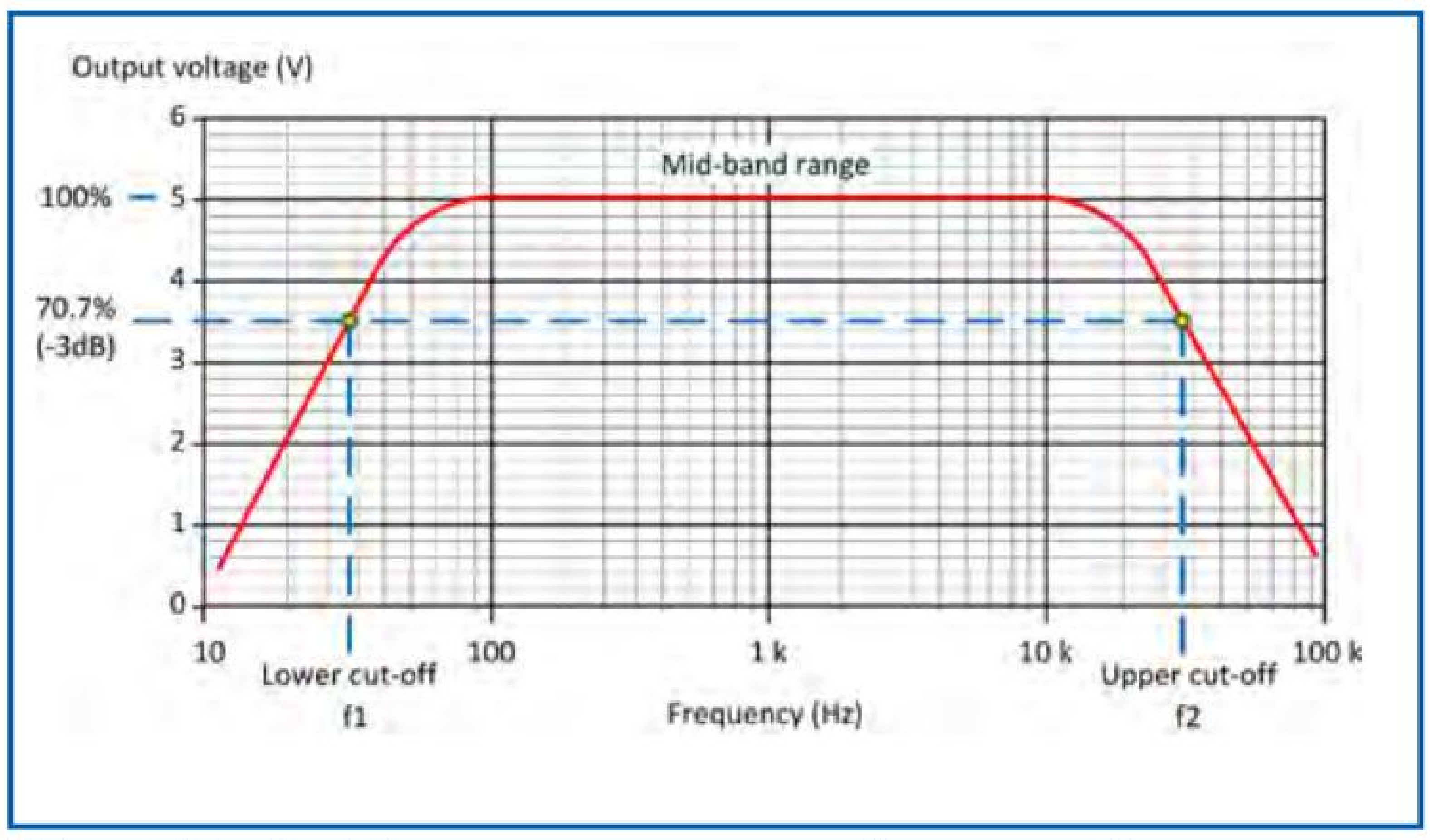


Fig.1.9 Typical frequency response for an audio power amplifier (note the logarithmic scale)

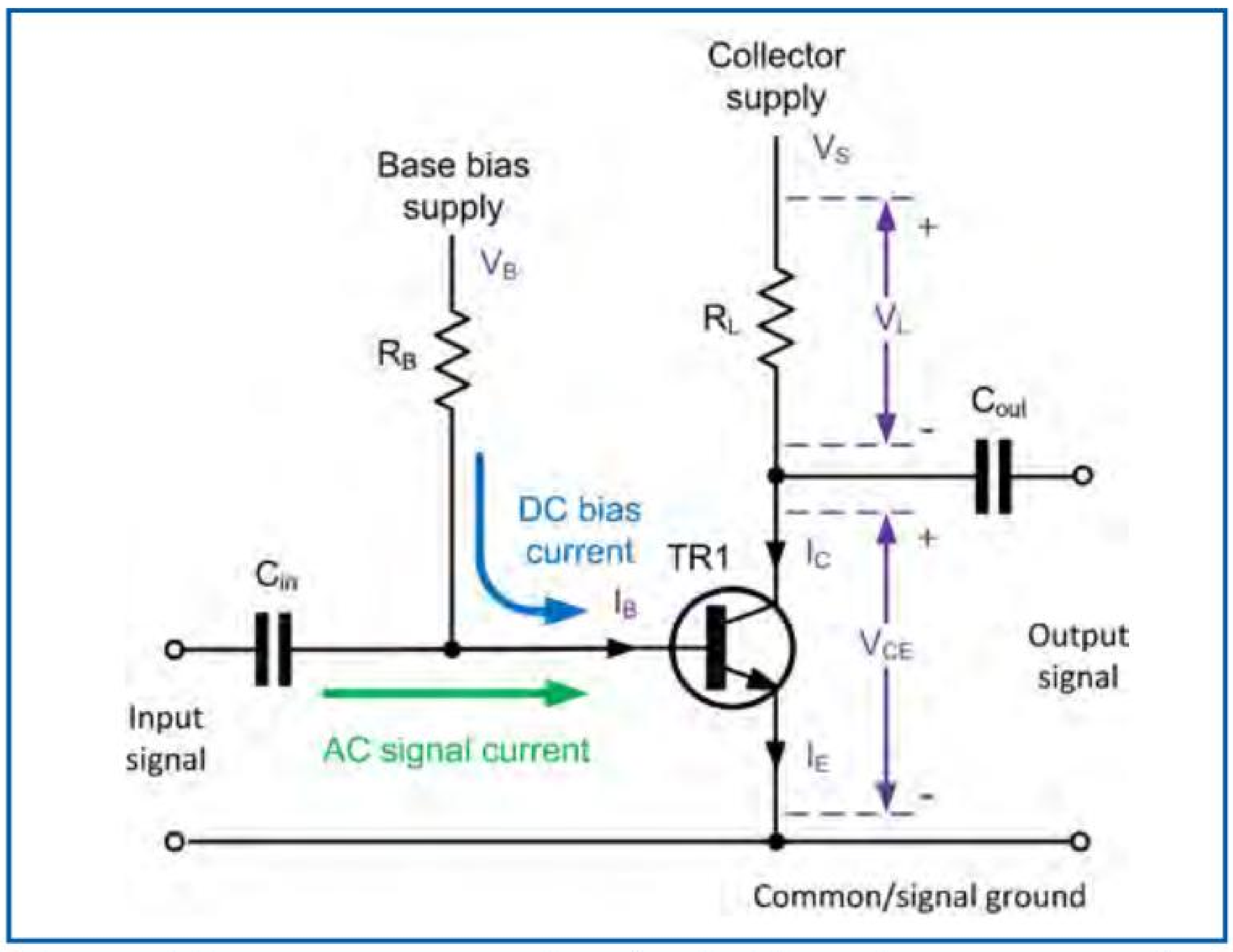


Fig.1.10 Bias arrangement in a basic Class-A common-emitter amplifier

by any device connected to the input. C_{out} couples the signal out of the stage and also prevents DC current flowing at the output terminals. It is important to note how the DC bias current and AC signal current merge together to form the base current for TR1. As a consequence of this, the collector current (a magnified version of the base current) will also have AC and DC components.

In order to stabilise the operating conditions for the stage and compensate for variations in transistor parameters, base bias current for the transistor can be derived from the voltage at the collector or from some later point in the case of a multi-stage amplifier (see *Get Real*). When derived from the collector, the bias voltage will be dependent on the collector current which, in turn, depends upon the base current. The result of this negative feedback is a degree of self-regulation; if the collector current increases, the collector voltage will fall and the base current will be reduced. The reduction in base current will produce a corresponding reduction in collector current to offset the original change. Conversely, if the collector current falls, the collector voltage will rise and the base current will increase. This, in turn, will produce a corresponding increase in collector current to offset the original change.

In the simple arrangement shown in Fig.1.10, let's assume that the collector supply is 8V, the base supply is 5V, and the value of R_L is 1kΩ. In order to produce the maximum undistorted output voltage swing, the ideal value of collector-emitter voltage would be 4V (half the supply) and so the collector current would be 4mA. If the transistor has a current gain of 200 (a reasonable assumption for most of today's general purpose devices) we would need to supply a DC bias current of 4/200 = 20µA to its base. Further, since the base-emitter voltage will be approximately 0.6V (recall that the base-emitter junction constitutes a conducting diode junction) the value of R_B would need to be 220kΩ in order to produce 20µA of bias current from the 5V base bias supply.

Now, suppose that an AC input signal of 15µA peak-peak is applied to the base of TR1 via coupling capacitor C_{in}. This signal would be amplified by the transistor and produce an output signal of 3mA pk-pk flowing in R_L (see Fig.1.11) The corresponding output voltage developed across R_L coupled via C_{out} to the output terminals would then be 3V pk-pk.

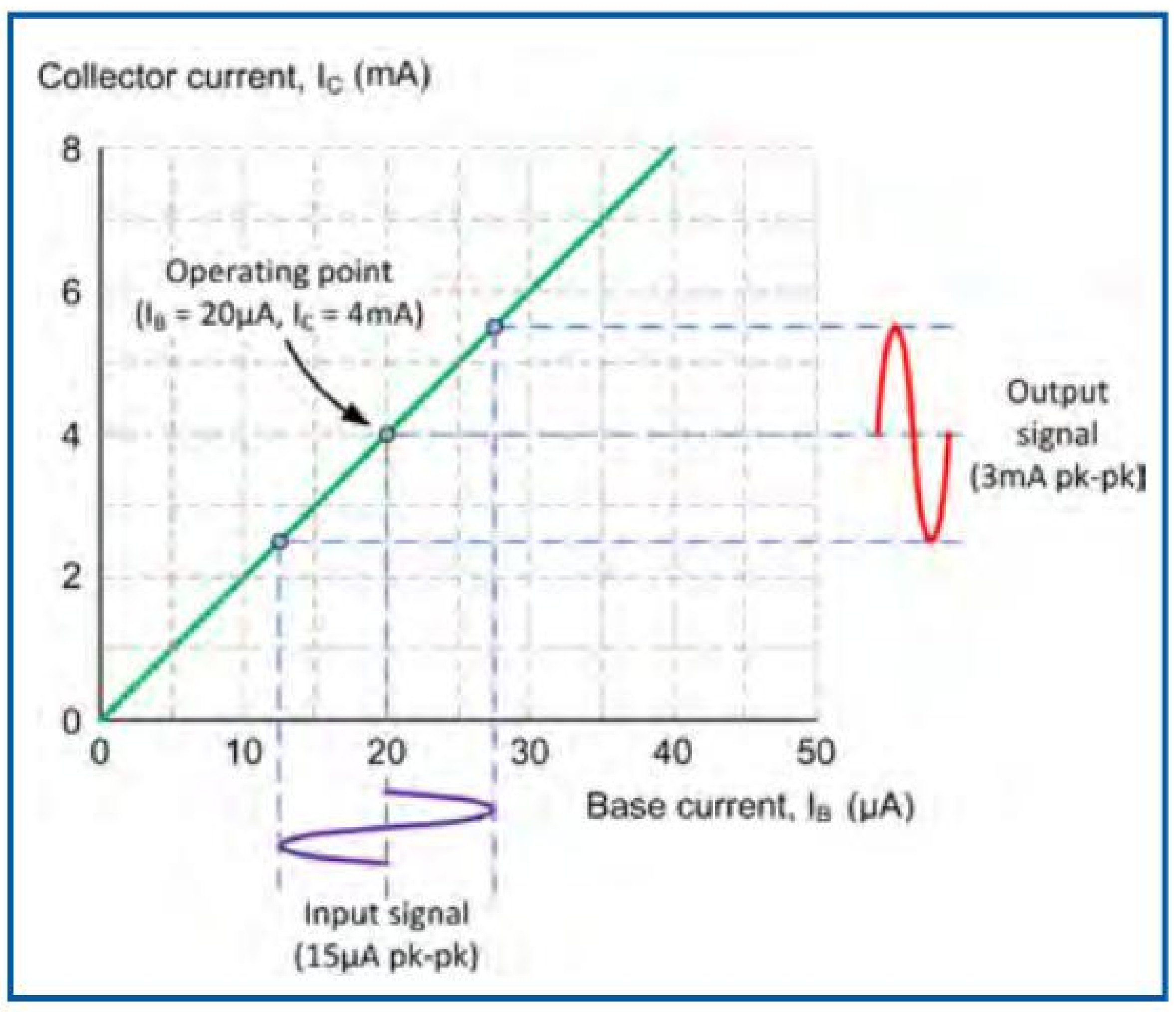


Fig.1.11 Input and output signals superimposed on the transfer characteristic of the BJT in Fig.1.1

Special Feature: Computer simulation

Computer simulation provides you with a powerful and cost-effective tool for designing, simulating, and analysing a wide variety of electronic circuits. In recent years, the computer software packages designed for this task have not only become increasingly sophisticated, but also have become increasingly easy to use. Furthermore, several of the most powerful and popular packages are now available at low cost either in evaluation, 'lite' or student versions. In addition, there are several excellent freeware and shareware packages. In *Teach-In 2015* we will be using the Student version of TINA Design Suite, a powerful and easy-to-use package from DesignSoft. A demonstration version of the full software (Tina 10.0 Design Suite) can be downloaded from **https://www.designsoft.biz/orders/order.php** and the Basic Edition and Student versions are both reasonably priced and are highly recommended. In fact, the authors have been using this software for well over ten years and have found it to be invaluable when designing and simulating a huge range of circuits, both analogue and digital.

TINA is available from the *EPE Online Shop* – see **www.epemag.com**.

Adding SPICE to your life

Early electronic simulation software required circuits to be entered using a complex 'netlist' that described all of the components and connections present in a circuit; however, most modern packages use an on-screen graphical representation of the circuit on test. This, in turn, generates a netlist (or its equivalent) for submission to the computational engine that actually performs the circuit analysis using mathematical models and algorithms. In order to describe the characteristics and behaviour of components such as diodes and transistors, a manufacturer usually provides models in the form of a standard list of parameters.

Most programs that simulate electronic circuits use a set of algorithms that describe the behaviour of electronic components. The most commonly used algorithm was developed at the Berkeley Institute in the United States and it is known as SPICE (Simulation Program with Integrated Circuit Emphasis).

Results of circuit analysis can be displayed in various ways, including displays that simulate those of real test instruments (these are sometimes referred to as 'virtual instruments'). A further benefit of using electronic circuit simulation software is that, when a circuit design has been finalised, it is usually possible to export a file from the design/simulation software to a PCB layout package. It may also be possible to export files for use in screen printing or CNC drilling. This greatly reduces the time that it takes to produce a finished and fully working prototype. Various types of analysis are available within modern SPICE-based circuit simulation packages and we will be taking a detailed look at them in a future instalment of *Teach-In 2015*.

Netlists and component models

The following is an example of a netlist for a simple differential amplifier (see Fig.1.12). Note that we have included line numbers purely for explanatory purposes:

```
1  SIMPLE DIFFERENTIAL PAIR
2  VCC 7 0 12
3  VEE 8 0 –12
4  VIN 1 0 AC 1
5  RS1 1 2 1K
6  RS2 6 0 1K
7  Q1 3 2 4 MOD1
8  Q2 5 6 4 MOD1
9  RC1 7 3 10K
10 RC2 7 5 10K
11 RE 4 8 10K
12 MODEL MOD1 NPN BF=50 VAF=50
   IS=1.E-12 RB=100 CJC=.5PF
   TF=.6NS
13 .TF V(5) VIN
14 .AC DEC 10 1 100MEG
15 .END
```

Lines 2 and 3 of the netlist define the two supply voltages. V_{CC} is +12 V and is connected between node 7 (positive) and node 0 (signal ground). V_{EE} is –12 V and is connected between node 8 (negative) and node 0 (signal ground). Line 4 defines the input voltage which is connected between node 1 and node 0 (ground) while lines 5 and 6 define 1 kΩ resistors (RS1 and RS2) connected between 1 and 2, and 6 and 0.

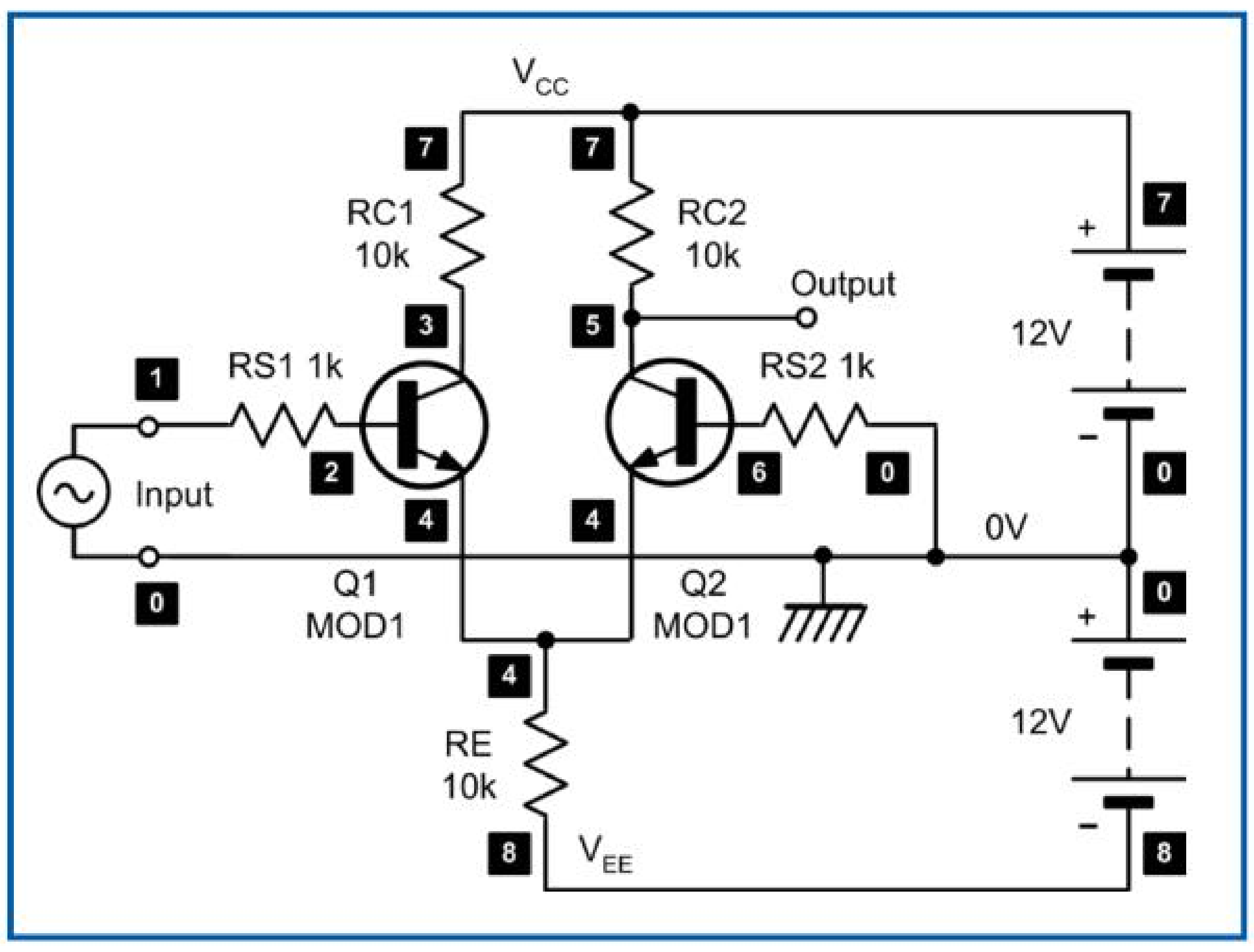


Fig.1.12 A simple differential amplifier showing the netlist nodes

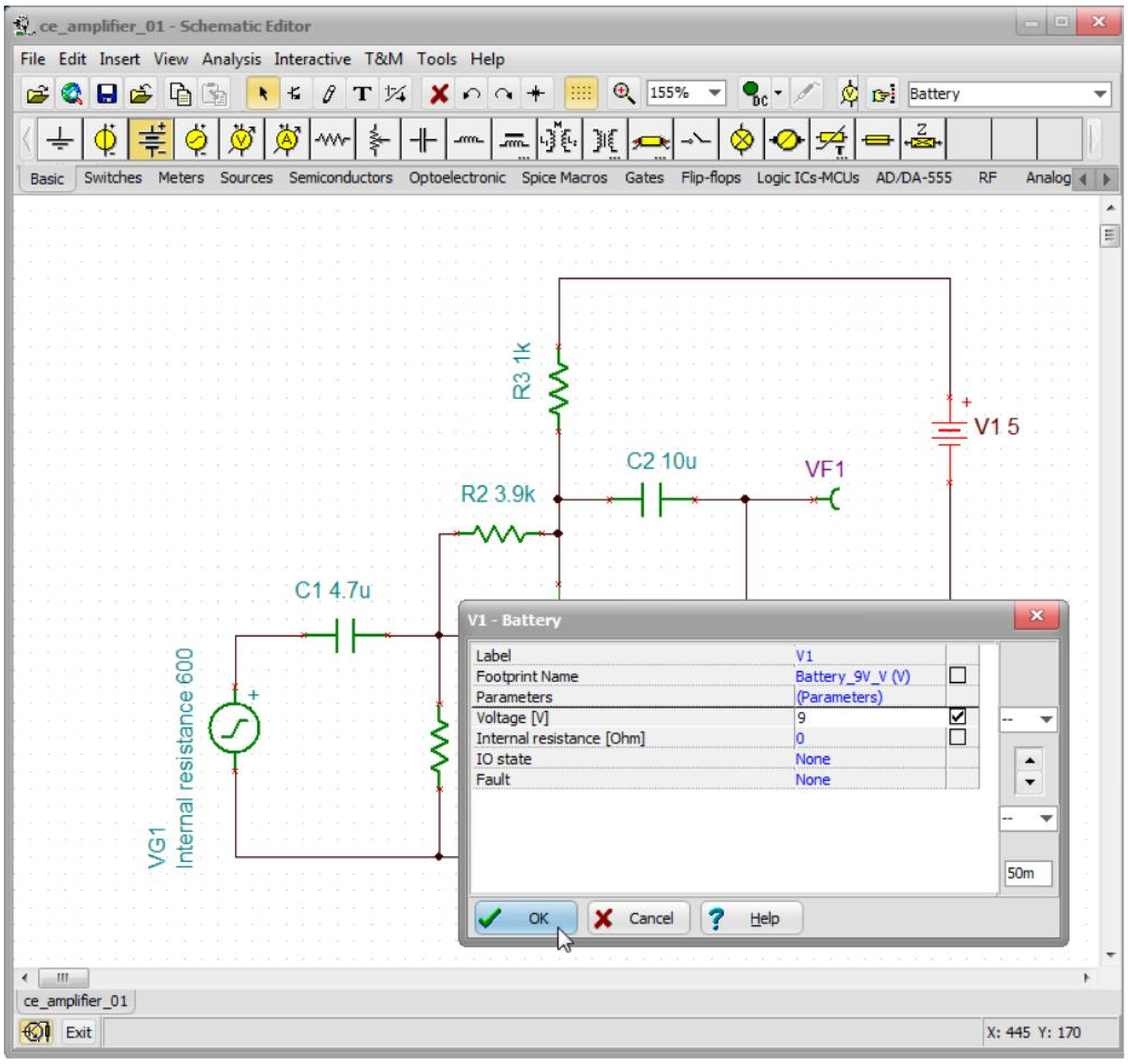
Lines 7 and 8 are used to define the connections of the two transistors (Q1 and Q2). The characteristics of these transistors (both identical) are defined by MOD1 (see line 12). Lines 9, 10 and 11 define the connections of three further resistors (RC1, RC2 and RE respectively). Line 12 defines the transistor model. The device is NPN and has a current gain of 50.

SPICE models

Most semiconductor manufacturers provide detailed SPICE models for the devices they produce. The following is a manufacturer's SPICE model for the BC549B transistor that we will be using in this month's *Teach-In 2015*.

```
.model  BC549B    NPN(Is=7.049f
Xti=3 Eg=1.11 Vaf=59.93 Bf=375.6
Ise=56.03f
+ Ne=1.553  Ikf=87.07m  Nk=.4901
Xtb=1.5  Br=2.886  Isc=7.371p
+  Nc=1.508  Ikr=5.426  Rc=1.175
Cjc=5.5p  Mjc=.3132  Vjc=.4924
Fc=.5
+  Cje=11.5p  Mje=.6558  Vje=.5
Tr=10n   Tf=417.3p   Itf=1.512
Xtf=39.51
+ Vtf=10)
```

At this stage, and if this is beginning to sound a little complicated, it's important to remember that there's no need to be able to understand the model in order to make good use of the device. Furthermore, the models that you need will almost certainly already be present in the simulation software that you will be using. This helps keep things simple!


ce_amplifier_01 - Schematic Editor
File Edit Insert View Analysis Interactive T&M Tools Help
155%
Battery
Basic Switches Meters Sources Semiconductors Optoelectronic Spice Macros Gates Flip-flops Logic ICs-MCUs AD/DA-555 RF Analog
R3 1k
V1 5
C2 10u
VF1
R2 3.9k
C1 4.7u
VG1
Internal resistance 600
V1 - Battery
50m
OK
Cancel
Help
ce_amplifier_01
Exit
X: 445 Y: 170

Label	V1	
Footprint Name	Battery_9V_V (V)	☐
Parameters	(Parameters)	
Voltage [V]	9	☑
Internal resistance [Ohm]	0	☐
IO state	None	
Fault	None	

Fig.1.14 Modifying the value of a component using a dialogue box (here, we are changing the default 5V battery so that it becomes the 9V supply in our circuit)

Getting started with TINA

TINA is distributed in two major versions, TINA Standard and TINA Design Suite. TINA Standard includes circuit simulation only, while TINA Design Suite also includes the advanced PCB designer. The software is supplied on CD or can be downloaded from the web and, whichever version is chosen, the installation procedure is extremely straightforward. You can specify the folders used by the program, the Settings folder stores your personal settings and the private catalogue folder will store your catalogue. By default, these are set to common Windows folders, however, you may change the folders by pressing the browse button. You will also be able to configure the software so that is uses either the US (ANSI) or the European (DIN) conventions for component symbols.

Screen layout

The main program window includes a conventional Windows menu bar that provides access to all of the main program functions, such as File, Edit, Insert, View or Analysis. Below this is a toolbar that provides access to some of the most commonly used editing features, such as cut, paste and zoom.

The component bar is located beneath the toolbar. The component bar provides access to the extensive library of components that is supported by TINA. Components are arranged in groups, named by the tabs on the Component bar. Once a particular group has been selected, the available components appear as a row of symbols immediately above the component tabs. The main schematic editor (from which the screen data is captured in order to generate the netlist) occupies the rest of the screen area.

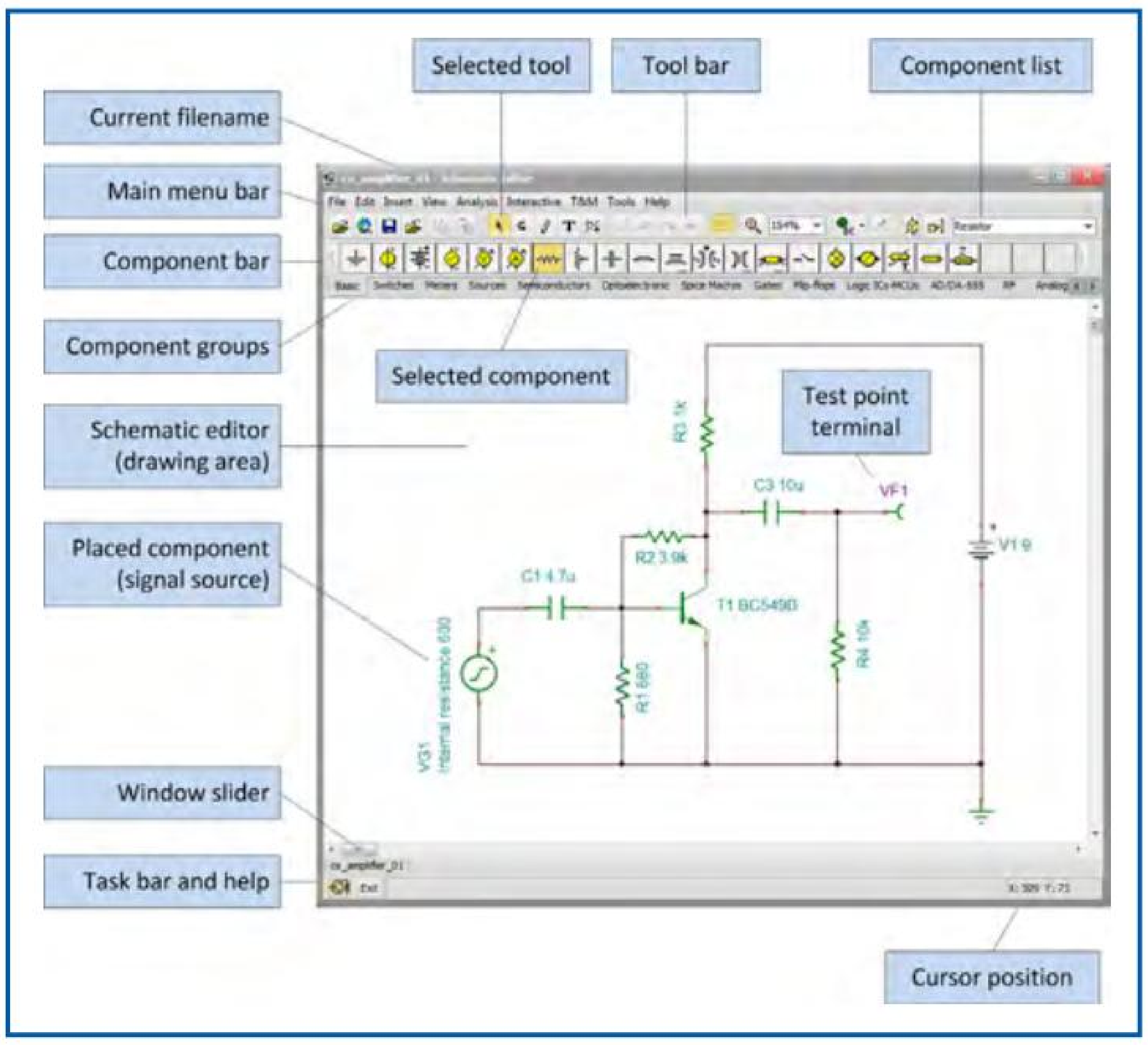

Selected tool
Tool bar
Component list
Current filename
Main menu bar
Component bar
Component groups
Selected component
Test point terminal
Schematic editor (drawing area)
Placed component (signal source)
Window slider
Task bar and help
Cursor position
R3 1k
C3 10u
VF1
V1 9
R2 3.9k
C1 4.7u
T1 BC549B
R4 10k
R1 680
VG1
Internal resistance 600

Fig.1.13 TINA screen layout

Selecting and placing components

When you click on a particular component in the toolbar (and then release the mouse button), the cursor changes to show the currently selected component. The component can be moved anywhere within the circuit drawing area of the screen. The component can then be rotated left or right by either right-clicking the mouse and selecting Rotate Left or Rotate Right from the context-sensitive menu or by pressing the Ctrl-L or Ctrl-R keys.

If you need to change the value of a component from the default value you can simply double-click on the component symbol and enter the required values in the dialogue box. When you click on OK the dialogue box will disappear and the component values will be updated on the screen. Once you have chosen the final position, orientation and value for the component you can simply click the left mouse button on a blank area of the drawing window in order to lock the symbol in place.

Having placed your components, the next step it to connect them together with wires. You can do this by selecting the component and locating the connecting point with the mouse (the cursor will change from a pointing finger to a wiring tool). Next, hold down the left mouse button and draw the wire you need and link it to the required connecting point on the component to which it is connected.

Table 1.3 Outline design specification for the pre-amplifier

Characteristic	Value
Voltage gain	25 (configurable from 10 to 50)
Frequency response	10Hz to 100kHz
Input impedance	20kΩ
Output impedance	30Ω
Maximum output	2V RMS into 10kΩ at 1kHz, 0.01% THD
Phase shift	180° at 1kHz (output inverted)
Supply voltage	9V at less than 5mA
Hum and noise	Better than –65dB (ref. 1V RMS, 100kHz bandwidth)

Testing a circuit

You can test your circuit using a variety of powerful analysis tools built into TINA. Later in *Teach-In 2015* we will explore several of these in relation to our *Get Real* projects. For the purposes of this gentle introduction we will focus our attention on carrying out a simple DC analysis of the example single-stage common-emitter amplifier circuit shown in Fig.1.15. However, before we carry out our analysis it is well worth running an electric rules check (ERC) which will scrutinise the schematic that we've entered by looking for questionable connections between components. To do this, you need to select ERC from the Analysis menu. A message will then appear which will alert you to any problems that will need correcting before you can continue with the analysis. If you then select Analysis, followed by DC Analysis and Table of DC results, the schematic editor will show the nodes in your circuit and a table of DC voltages and currents will appear like that shown in Fig.1.15 and 1.16.

Get Real: A simple pre-amplifier

Our first *Get Real* project is a simple pre-amplifier that can be used in a variety of practical applications, including simple 'signal boosters', microphone pre-amplifiers, and measurement systems. The circuit was developed to satisfy the outline design specification shown in Table 1.3. It should produce a modest amount of voltage gain (around 25) over a wide range of frequencies extending from less than 10Hz to around 100kHz. Another important requirement is the ability to easily tailor the voltage gain and frequency response.

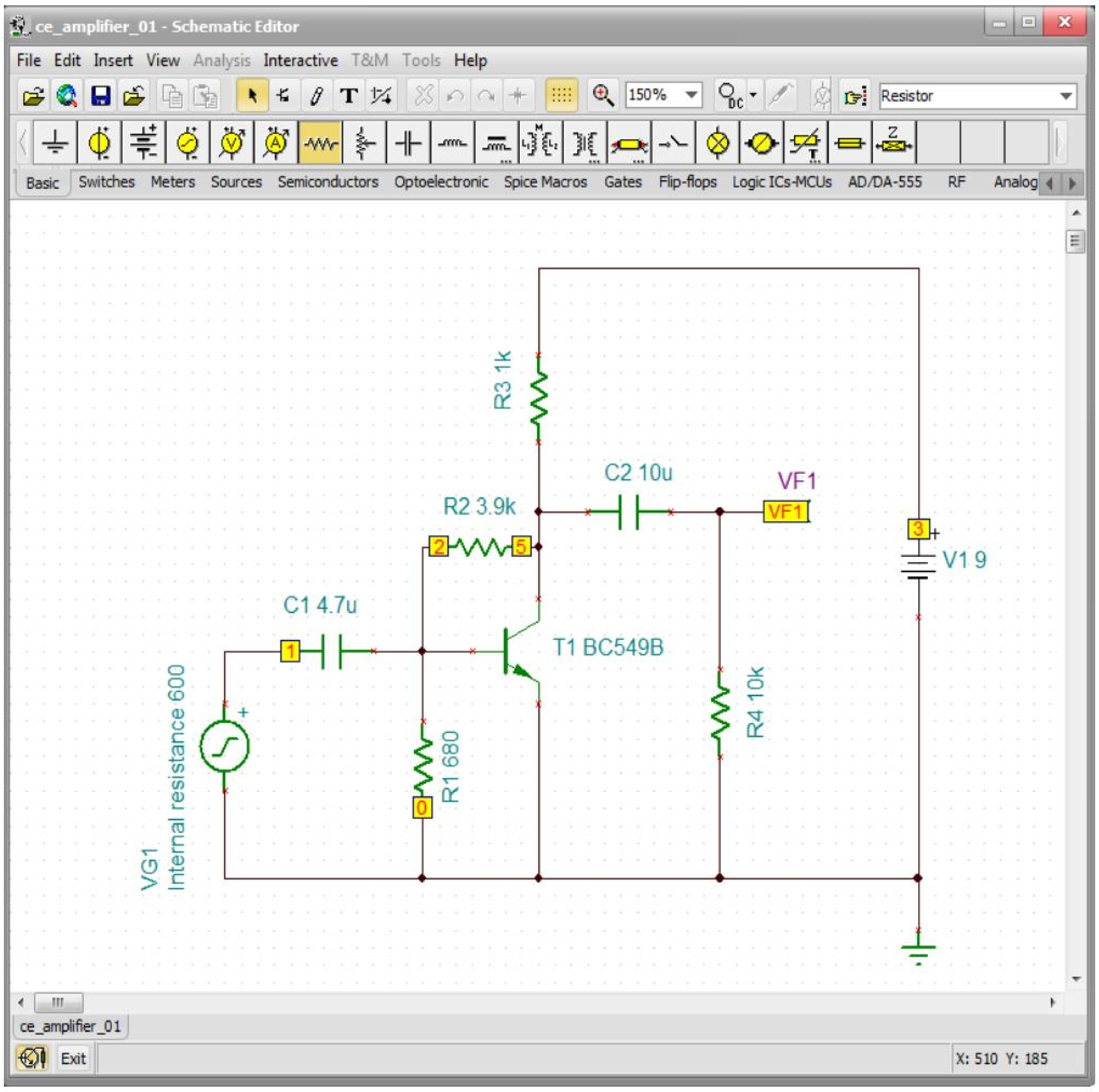

ce_amplifier_01 - Schematic Editor
File Edit Insert View Analysis Interactive T&M Tools Help
150%
Resistor
Basic Switches Meters Sources Semiconductors Optoelectronic Spice Macros Gates Flip-flops Logic ICs-MCUs AD/DA-555 RF Analog
R3 1k
C2 10u
VF1
R2 3.9k
2
5
3
V1 9
C1 4.7u
1
T1 BC549B
R4 10k
VG1
Internal resistance 600
R1 680
0
ce_amplifier_01
Exit
X: 510 Y: 185

Fig.1.15 Nodes defined when carrying out a DC analysis of the single stage common-emitter amplifier

Circuit description

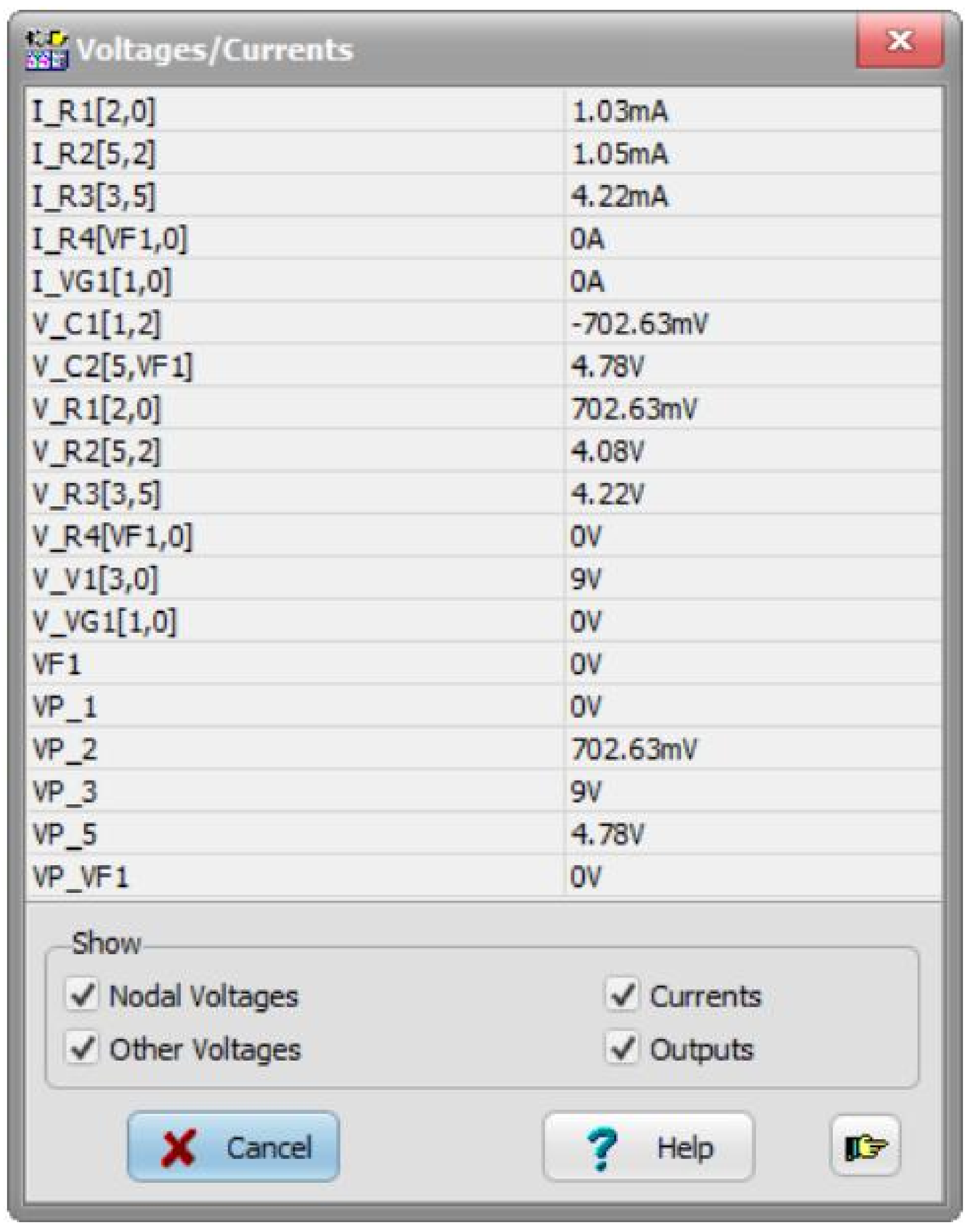
The complete circuit diagram of the pre-amplifier is shown in Fig.1.17. The circuit uses two transistors, TR1 and TR2. The first stage, with TR1 and associated components, operates in common-emitter mode and provides both current and voltage gain. This is followed by the second stage (TR2 and associated components) which operates as an emitter follower, providing appreciable current gain along with a voltage gain of only slightly less than unity (one). The overall voltage gain of the circuit is thus largely determined by TR1 but, since the output impedance is quite low, the circuit will happily drive a wide range of load impedances.

Base bias for the first stage, TR1, is derived via R3 from the current flowing in the second stage (see *Knowledge Base*). Feedback also helps to stabilise the overall voltage gain and DC operating conditions and allows the circuit to work with a wide range of NPN general-purpose small-signal transistors.

Coupling

The input signal is coupled into the pre-amplifier by means of C1 and output signal is coupled to the load by means of C3. These two capacitors provide DC isolation for the pre-amplifier so that the DC bias current and voltages for TR1 and TR2 are unaffected by whatever DC conditions are present at the input and output. In most cases it is expected that as far as DC levels are concerned, the input and output are at ground potential. If this is not the case then it may become necessary to uprate the working voltage of the relevant coupling capacitors.

Within the pre-amplifier, the signal is directly coupled from TR1 to TR2 and there is no need for isolation between these internal stages. Note that, in high-gain multi-stage amplifiers, internal isolation between stages may sometimes become essential due to complications with biasing and the need to avoid drift in DC potentials which might occur due to temperature changes.



```
I_R1[2,0]       1.03mA
I_R2[5,2]       1.05mA
I_R3[3,5]       4.22mA
I_R4[VF1,0]     0A
I_VG1[1,0]      0A
V_C1[1,2]       -702.63mV
V_C2[5,VF1]     4.78V
V_R1[2,0]       702.63mV
V_R2[5,2]       4.08V
V_R3[3,5]       4.22V
V_R4[VF1,0]     0V
V_V1[3,0]       9V
V_VG1[1,0]      0V
VF1             0V
VP_1            0V
VP_2            702.63mV
VP_3            9V
VP_5            4.78V
VP_VF1          0V
```

Show
☑ Nodal Voltages ☑ Currents
☑ Other Voltages ☑ Outputs

Fig.1.16 Table of DC results for single stage common-emitter amplifier

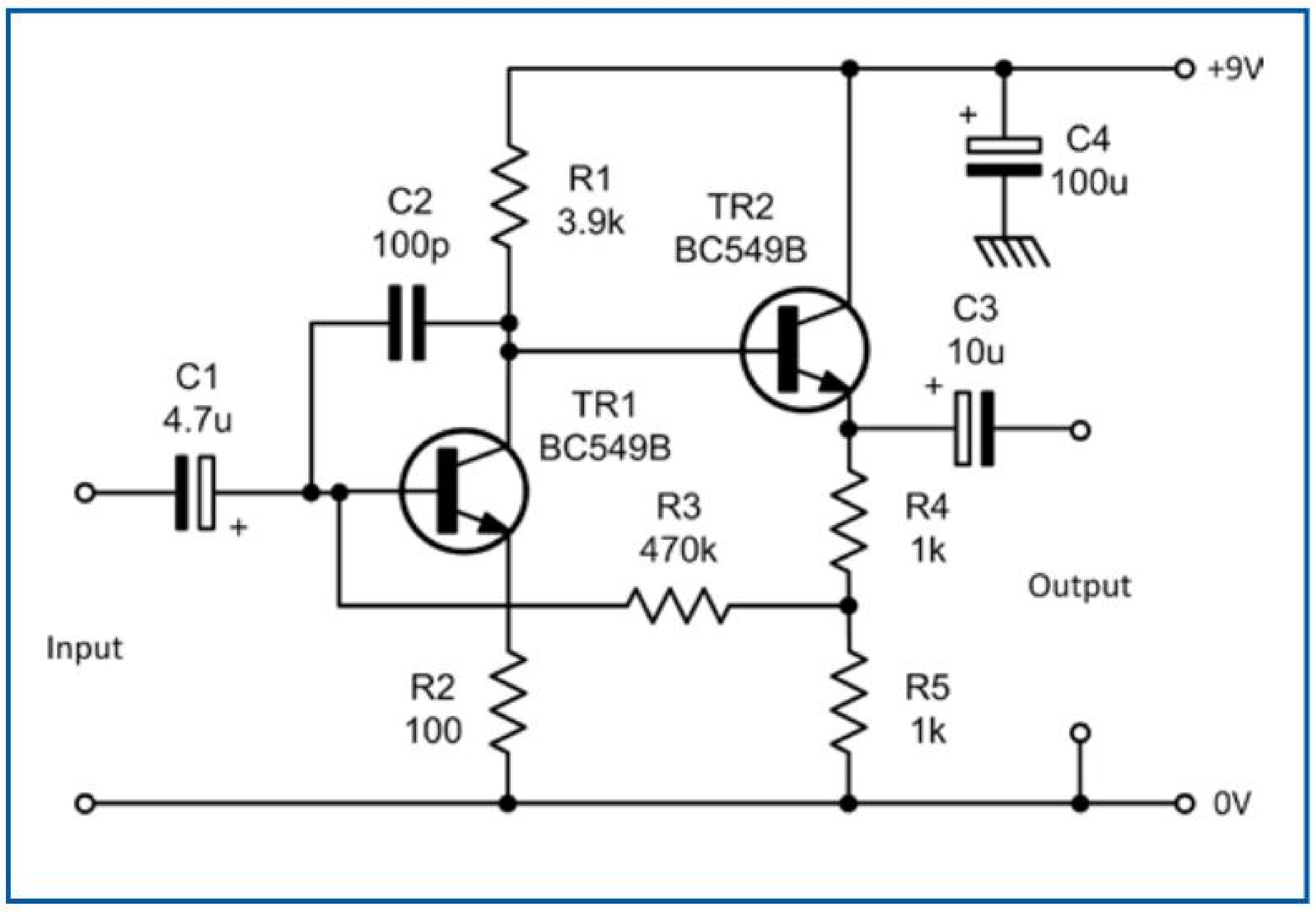


Fig.1.17 Circuit of the versatile pre-amplifier

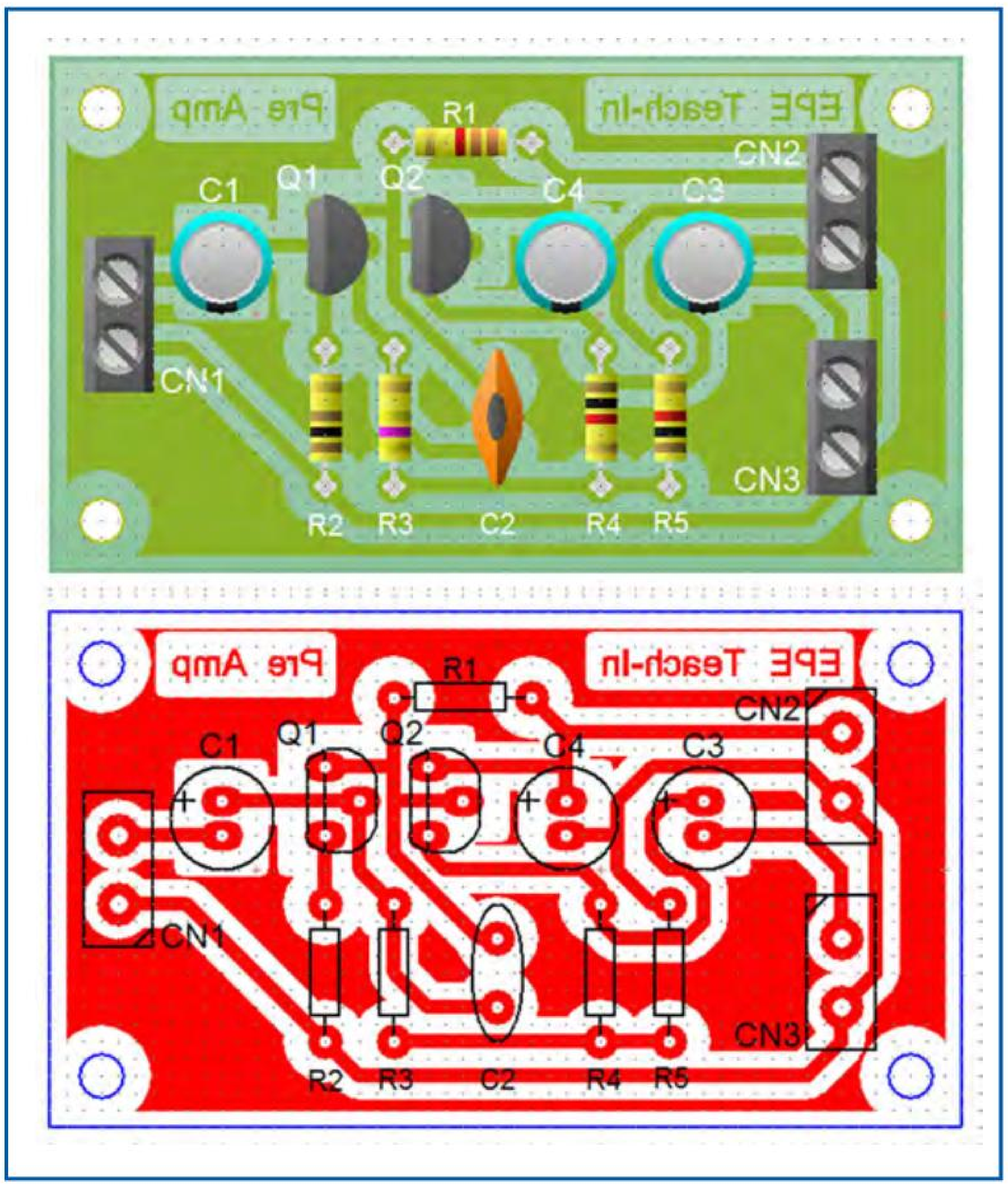


Fig.1.18 PCB artwork showing real world and PCB views

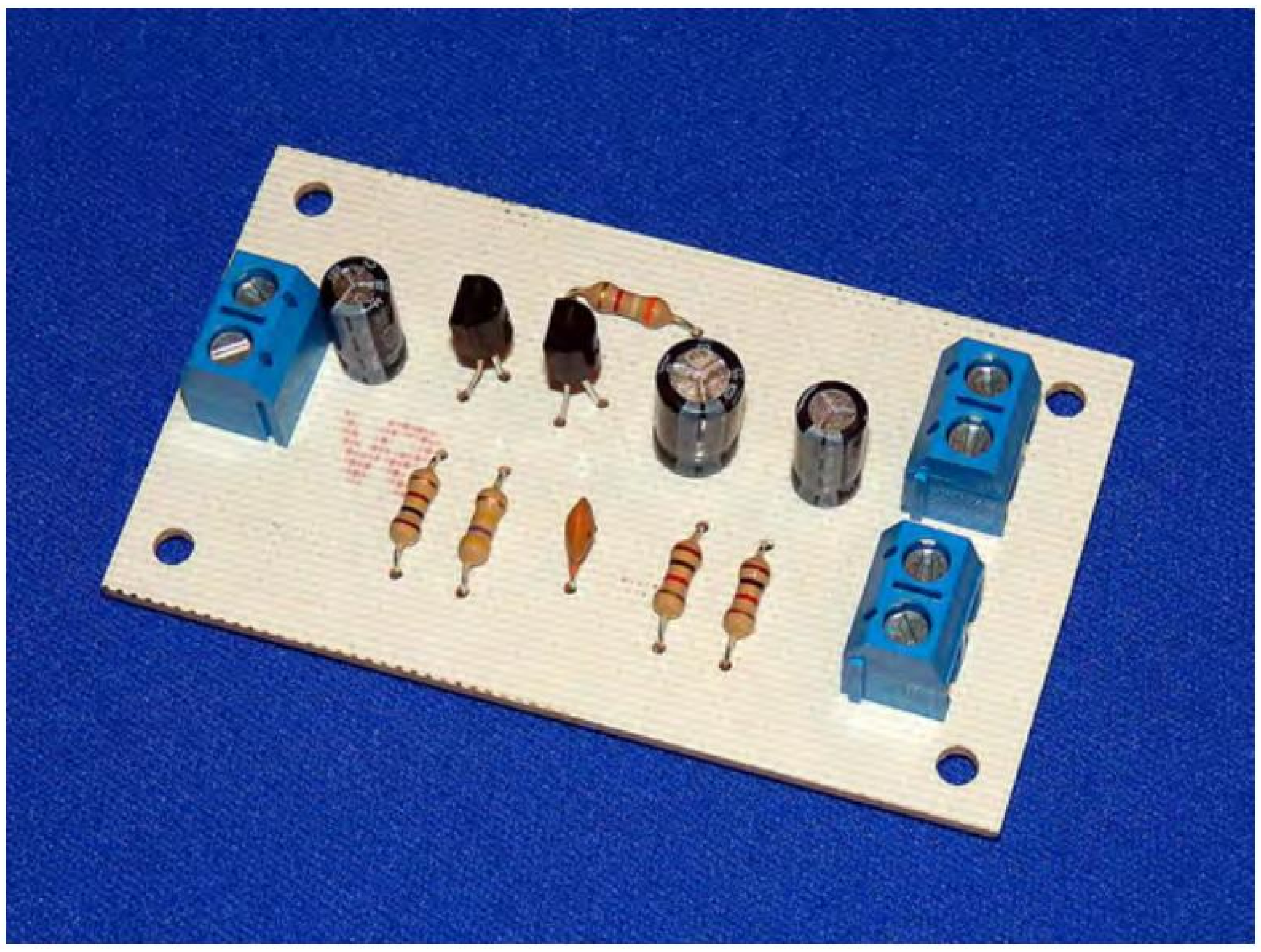


Fig.1.19 Completed pre-amplifier circuit ready for testing

Gain adjustment

Voltage gain is reduced by introducing series current negative feedback to TR1 by means of the fixed resistor, R2. The value of this component can be varied over the range zero (short-circuit) to around 330Ω to produce a voltage gain of 90 to 10, respectively (more on this in next month's *Teach-In 2015*).

Frequency response adjustment

The lower frequency cut-off is determined mainly by the value of C1 and the upper frequency cut-off response (using shunt voltage negative feedback) by the value of C2. In next month's *Teach-In 2015* we will show how the values of these components can be changed to define appropriate lower and upper cut-off frequencies for use in different applications.

Components

1 PCB, code 905 available from the *EPE PCB Service*, size 68mm × 40mm,
3 PCB mounting 2-way terminal blocks
1 PP3 battery connector
1 SPST on/off switch

Resistors
1 3.9kΩ (R1)
1 100Ω (see text) (R2)
1 470kΩ (R3)
2 1kΩ (R4, R5)
All resistors 0.25W 5%

Capacitors
1 4.7µF (see text) (C1)
1 100pF (see text) (C2)
1 10µF (C3)
1 100µF (C4)

Semiconductors
2 BC549B (see text) (TR1, TR2)

Choice of transistor

We selected BC549B transistors for use in the pre-amplifier circuit. They are from the B-gain group of BC549 devices (see *Discover*) and they offer low-noise performance, which is important when an amplifier stage is used with signals of low amplitude (less than 10mV, or so). As discussed, it is possible to use a wide range of other devices for TR1 and TR2 including BC548B (where low noise performance is unimportant), BC237, BC182, BC167, NTE123AP, and BC550 as well as most other NPN small-signal transistors. In all cases it is important to check on the device pin-out before making a substitution.

Construction

Our prototype printed circuit board (PCB) was designed to be built into a small enclosure or incorporated into a larger enclosure with other circuits – it measures 68mm × 40mm. The PCB component layout and copper track layout was produced using Circuit Wizard (see next month for details) and is shown in Fig.1.18. The board can be purchased, ready drilled, from the *EPE PCB Service*, code 905 Our finished prototype, ready for testing, is shown in Fig.1.19.

Next month

In next month's *Teach-In*, *Get Real* we will show you how we used our favourite software applications, TINA and Circuit Wizard, to design, analyse and construct the pre-amplifier module. We will also show how the project can be configured for use in a variety of different applications. If you've built your own version of our *Get Real* project you will be able to put what you've learned into practice by following our examples and carrying out your own measurements.

To help you with this, *Discover* will introduce you to some powerful virtual instruments that will generate and display test signals. All you will need is an ordinary PC fitted with a sound card and some test leads. *Knowledge Base* will explain hybrid parameters and show you how they can be used to predict the performance of a transistor amplifier. For good measure, our *Special Feature* will show you how you can use Circuit Wizard to design your own printed circuit boards.

NET WORK

by Alan Winstanley

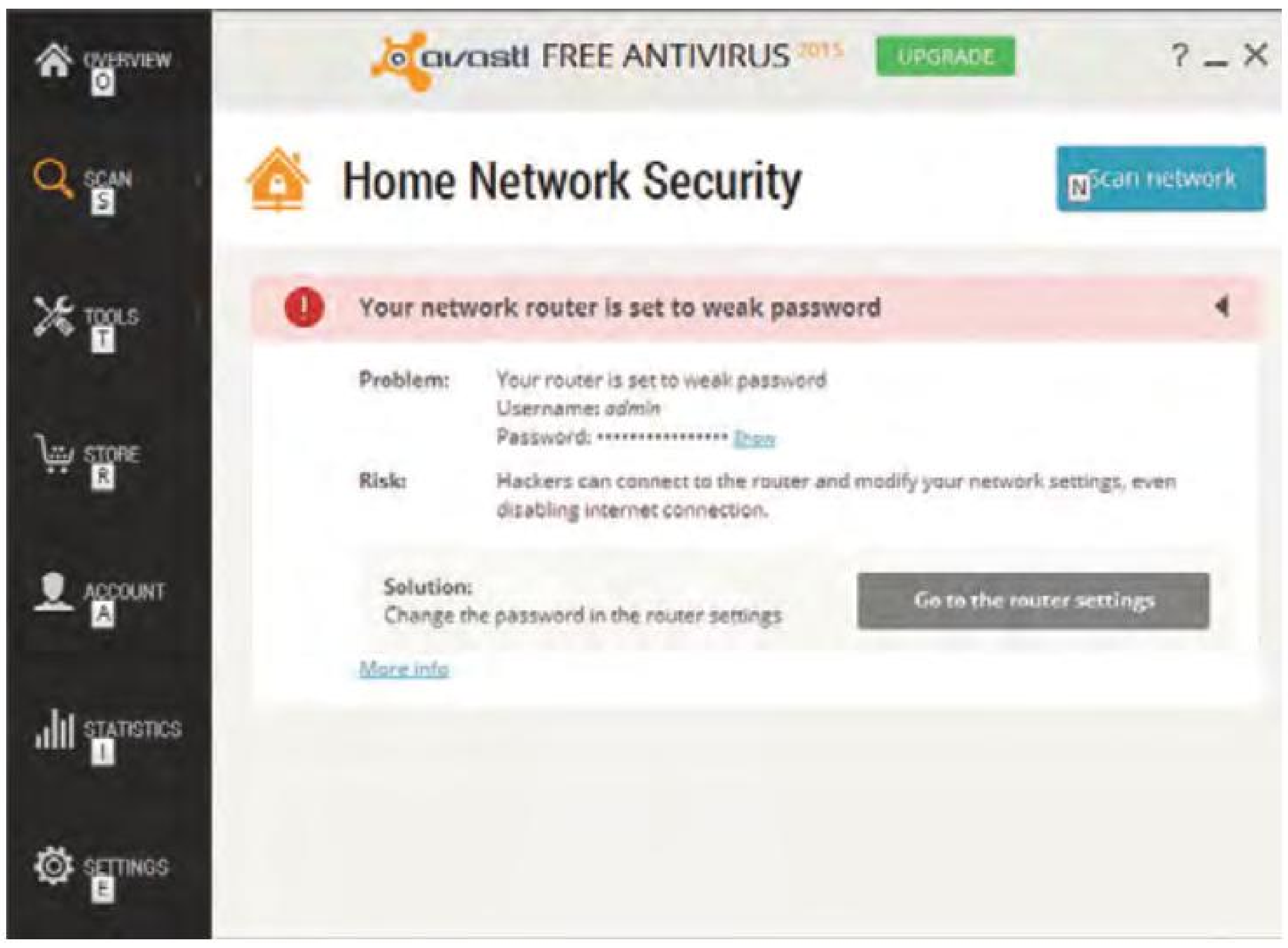
Avast, LAN-lovers!

IN the January 2014 *Net Work*, I revisited the perennial problem of protecting a PC from its Internet-based adversaries. Previously, I had suggested AVG Anti Virus, but with Christmas looming (and staying true to my Yorkshire roots) I baulked at the renewal costs for several PCs and so it was time to check out some alternatives. This time, I opted for the free version of Avast Anti-Virus from **www.avast.com** to protect my PC for the coming year.

I first suggested Avast in *Net Work* ten years ago, at a time when branded AV software usually arrived in yellow shrink-wrapped retail boxes with a CD and slender manual nestling inside. Back then, I claimed that highly effective software could also be downloaded free from the web, and the relatively unknown Avast was short-listed as a suitable candidate. A quick search of my email produced an unflattering follow-up from a *Net Work* reader in 2005, who soundly berated me for suggesting the hitherto unheard-of Avast program, which he blamed for wrecking his Windows system. I reaffirmed that I'd tested it on five PCs long before it reached *Net Work* and I suspected that in his case, Avast had not installed itself properly to begin with. It turned out that he was still running both AVG and Zone Alarm, so Avast was probably not the cause of his woes, and it is never good practice to run several AV programs side by side anyway.

AVG from hell

This brings me to up to date, when I recently attempted to uninstall AVG from an XP Professional machine before installing Avast. What should have been a simple task became a day-long nightmare as the stubborn software resolutely refused to depart from my disk. Freezes, lock-ups and nasty cycles of constant rebooting made the day a miserable one. AVG would not uninstall properly, nor would it re-install again either. It showed all the symptoms of leaving behind some digital detritus from several years' worth of updates and I had to become familiar with Windows XP Safe Mode once again. A scan with Malwarebytes also failed to complete: it could not update itself and the PC kept blue-screening and crashing, and then it got stuck in a loop of constant reboots.



Home Network Security

Your network router is set to weak password

Problem: Your router is set to weak password
Username: admin
Password: ••••••••••••••••

Risk: Hackers can connect to the router and modify your network settings, even disabling internet connection.

Solution:
Change the password in the router settings

Avast 2015 Home Network Security is currently the only anti-virus program that scans your home router for weaknesses

Blue screens and rebooting sometimes indicate a RAM problem, so I carefully reseated them. A free memory checker such as MemTest from **www.hcidesign.com** also drew a blank. Only by using AVG's last-resort uninstaller tool (**www.avg.com/gb-en/utilities**) did I finally manage to cure the problem, and this was a protracted process… and yet, AVG uninstalled effortlessly on another XP system without an issue. A freeware uninstaller tool such as Revo Uninstaller – tread carefully on their website – is also excellent at removing programs and cleaning up the registry afterwards.

No sooner was Avast installed than a new 2015 version downloaded itself along with an interesting new feature: Avast's **Home Network Security** tool will scan your network looking for vulnerabilities, and it will also scan your router. Avast 2015 claims to be the only AV program that does this, so I tried it out on several systems. In one case, the software highlighted that the default router password was weak, and it cleverly offered to visit the router's login page to help you change it. In a separate trial, Avast claimed the router was using old firmware. 'Flashing' an ADSL router is a job best not done in haste, but updating a router's firmware can often improve performance and cure annoyances such as dropped connections. Avast is a highly rated anti-virus program that is well worth testing, and the Home Network Security scanner is another welcome tool that will help keep our surfing safe.

What's the risk?

Using weak default logins on systems, routers, wireless access points and NAS drives is potentially very insecure, as a recent scandal about domestic IP webcams proved. A Russian programmer did us all a favour by listing many such vulnerable webcams on a website (now defunct) to show how easy it was to find a certain character string containing default webcam configurations, which permitted instant access to the video feed. I soon found some fairly innocuous British IP cameras that spied on residential driveways, parked cars or back yards, and I agree with the Russian programmer that the public needs to know about such problems in order to rectify them. The purpose of GeoIP is to match a device's IP address with its geographical co-ordinates for possible plotting on a map, so you can guess the location from an IP address too. However, as I showed in May 2012's *Net Work*, the results can be highly misleading. GeoIP is used by some e-commerce sites to combat credit card fraud though.

By gunning for a router's default configuration settings, hackers can access your network via the LAN, or possibly a wireless access point, or from outside via the WAN (Internet) itself. Such attacks can initially arrive in a virus or Trojan brought in via email, an infected USB memory key or a visit to a compromised website, and while such attacks are quite rare they are worth knowing about. In an extreme case, innocent network users could be re-directed to phoney copies of websites, such as online banks where login details could be captured. (Rapport software by IBM-owned Trusteer is designed to guard against this, and is often provided free by banks, and devices such as HSBC's security keypad improve security immensely.) Otherwise, all manner of exploits such as keylogging, botnet spamming or identity theft could be executed on a compromised system, or your router could be used to overload other addresses as part of a distributed denial of service (DDoS) attack. Sophisticated hackers running botnets can make your infected PC wake up on demand and start attacking IP addresses without you ever knowing.

You've got ten guesses

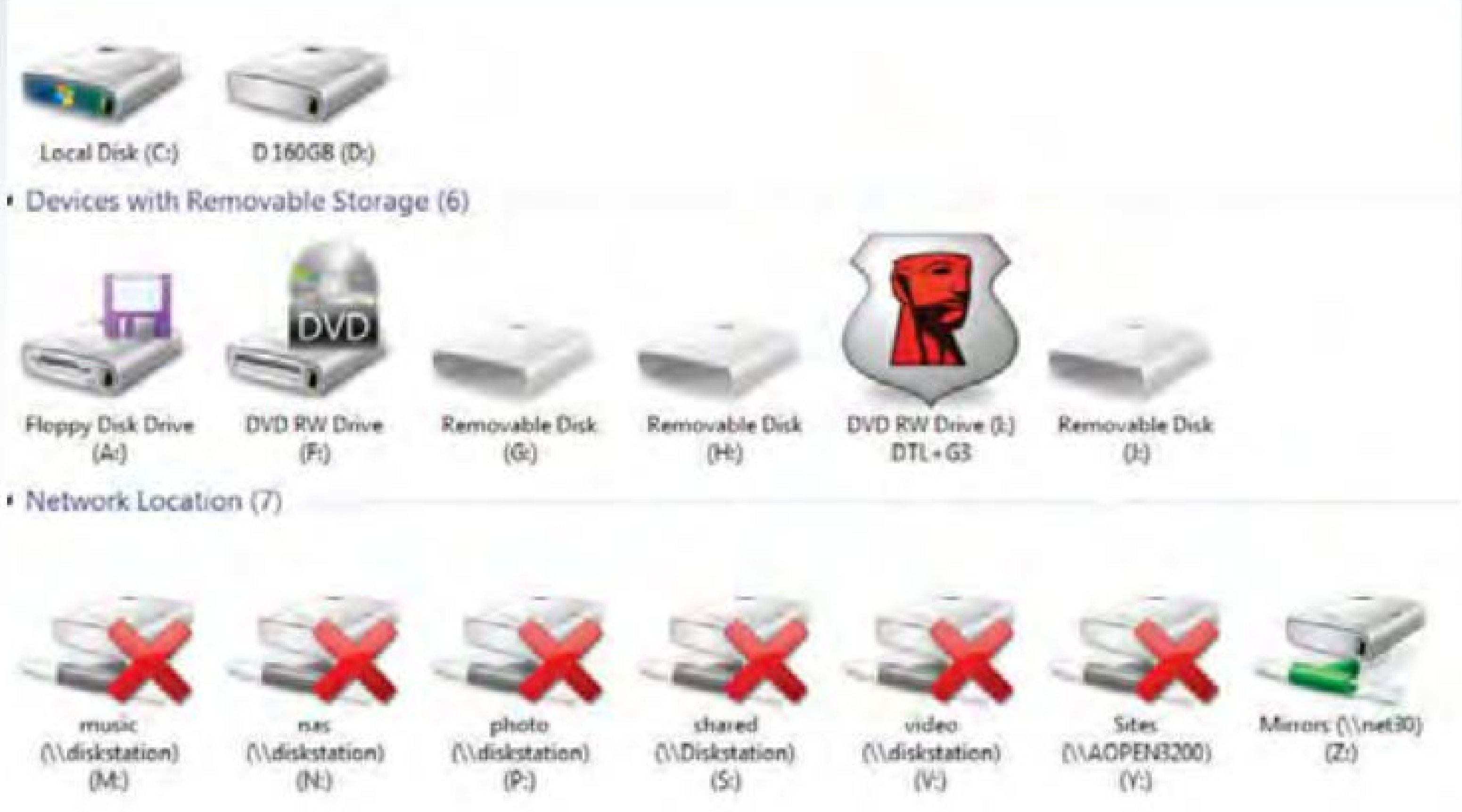
I often cringe with horror when I work on other IT systems, only to find that passwords are scribbled on a nearby Post-It note or easily-guessed passwords are used instead. Operators want the best of both worlds, the virtuous feeling of 'security' together with the convenience of something easily remembered (hacked). Even 'munged' or disguised passwords like `p@$$w0rd` can now be guessed by hackers performing a brute-force dictionary attack. Password managers, such as my preferred Roboform (**www.roboform.com**) can generate and store complex website logins securely, and a handy tip is to add a punctuation symbol on the end to make passwords an order of magnitude harder to guess.

Roboform also offers a cloud-based system of storing logins, but I have yet to overcome my nagging doubts about online security and eavesdropping, so instead I looked at ways of physically transporting my logins securely. I previously used the excellent Sandisk Cruzer Profile biometric memory key, which had a built-in fingerprint scanner. With a quick swipe I could unlock and launch Roboform from the USB key and then log into websites securely when I was out and about. Sadly, it is not supported in Windows 7 so I recently tried a **Kingston DataTraveler Locker+ G3**, a USB3 memory key with some beneficial features. It's metal-clad and therefore very robust for life on the road, but it also features both hardware encryption of data and password protection of its contents. By plugging it into a Windows 7+ PC or a Mac OSX computer, a login window pops up and offers users ten chances to enter the correct password. If they fail to do so, the encrypted data is erased and the drive reformats itself automatically. Not even its rightful owner can recover data from a wiped memory key.

64GB
DataTraveler®
LOCKER+ G3

The Kingston DataTraveler Locker+ G3 is a metal-clad USB3 memory key with hardware encryption and password protection

Although I configured the password protection successfully, I was disappointed that the Kingston DataTraveler Locker G3 proved temperamental on my own Windows 7 system. This is because the USB memory key requires two consecutive drive letters and Windows can be stubborn in the way it allocates them. Kingston explained to me that virtual drives or network shares can throw the system out if the memory key cannot obtain two physical drive letters (one for the launcher which then becomes redundant, and the other for the encrypted area). Windows can sometimes shuffle drive letters around and so the secured memory key may not launch properly. DVD drives or card reader drive letters can especially cause drive letter conflicts, as can be seen in the screenshot, with my USB key behaving like a DVD drive. (A handy shortcut to Windows Explorer that I use constantly is to press the Windows key + E.)

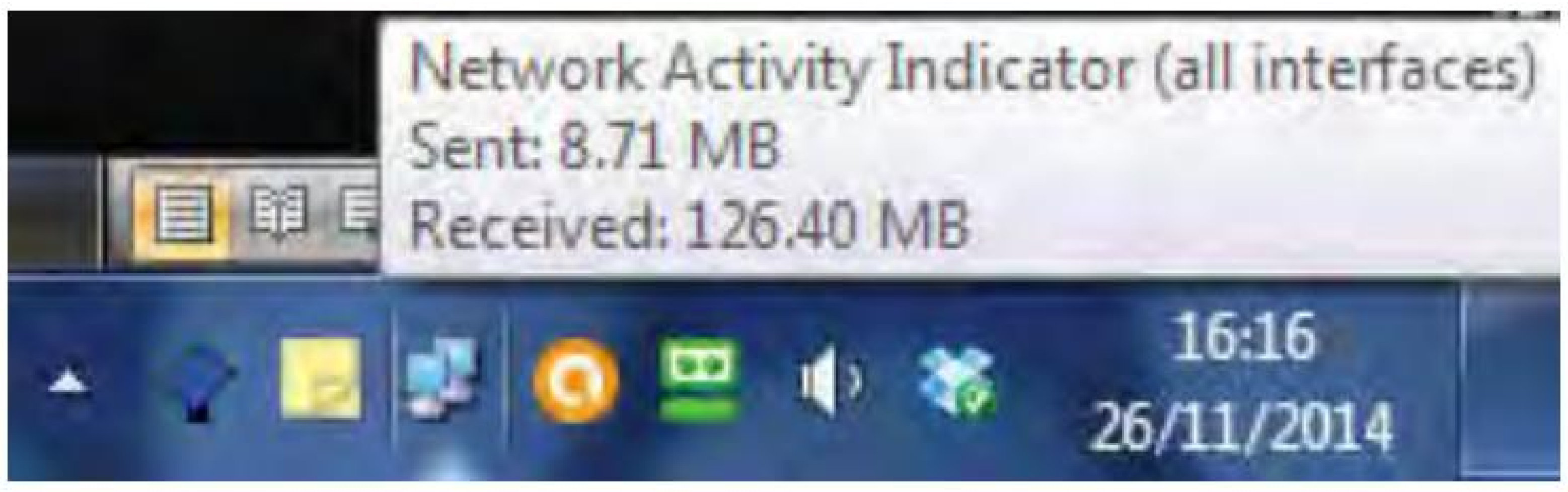


The DataTraveler Locker+ needs two consecutive physical drive letters which may conflict with other drives until configured

These caveats detract from the USB3 memory key's portability, which is a shame because it has some attractions, but it may still be perfectly fine for home PCs or Macs once the drive letters have been suitably nailed down. Windows users can check or change drive letters by going to: **Start/Control Panel/Administrative Tools/Computer Management/Storage/Disk Management**. The Kingston DataTraveler Locker+ G3 is available from Amazon in capacities of 8GB to 64GB.

Network Icons for Windows 7

One of the Windows XP features I've missed the most in Windows 7 is the small monitor icon in the system tray that flickered whenever there was network activity. Its sole purpose was to show that something was happening: maybe checking mail or downloading a file, but if my browser had frozen and the monitor icons were blank then I knew a wheel had fallen off the system somewhere.


Network Activity Indicator (all interfaces)
Sent: 8.71 MB
Received: 126.40 MB

Network Activity Indicator restores the monitor symbols in Windows 7 (right-click for more options). Download from ITSamples.com

Windows 7 users who feel the same way might like 'Network Activity Icon' supplied free by **www.itsamples.com**, which restores those enlightening symbols. Simply point it to your NIC (network card) and watch the monitors beam into life as traffic passes to and fro. If the icons are not visible, remember that they can be dragged from the 'hidden icons' area (click the 'Show hidden icons' triangle button nearby) and dropped onto the system tray where they can be viewed full time. The program is written by Igor Tolmachev, whose website offers a variety of handy little utilities including Caps Unlocker, which reverts a PC Caps Lock key after a delay and, as I have just discovered, it is a real boon for someone striving to meet a copy deadline!

In next month's *Net Work*, I will show how to see what your network is actually doing, using a free software tool, and I'll look at some ideas for self-publishing material in paperback form. Whether you're a budding novelist or want to indulge a passion or hobby, there's no need to sell out to a book publisher when you can do it yourself. Plus, I will suggest one or two easy ways of harnessing the web to get your work into print. You can email the writer at: **alan@epemag.demon.co.uk**.

By Robert Penfold

INTERFACE

Pi serial A/D converter

THE previous *Interface* article covered a simple 8-bit analogue-to-digital converter for use with the GPIO port of a Raspberry Pi computer. This circuit used parallel interfacing to the GPIO port. Here we move on to a 12-bit analogue-to-digital converter that uses an MCP3201 chip, together with a form of serial interfacing. Most of the early computer interfacing chips used parallel interfacing, but the serial approach now seems to be the generally preferred method. Comparing the 8-pin MCP3201 with the 20-pin AD7822BN used in the 8-bit converter (Fig.1) it is easy to see why. The parallel 8-bit converter chip has 2.5 times as many pins as the 12-bit serial device.

With parallel processing it is necessary to have an eight-wire connection in order to transfer bytes of data. Typically there would also be one or two control lines to regulate the flow of data, plus an earth (ground) connection of course. This equates to a total of about ten or eleven lines to swap bytes of data. An extra four or eight lines respectively are needed in order to transfer 12-bits and 16-bits of data at a time.

Bit by bit

There are two type of serial interfacing, synchronous and asynchronous. The once-popular but now largely defunct RS232C serial interface is an example of an asynchronous system. The data is transmitted one bit at a time on a single data line, with additional bits being used to indicate the beginning and end of each byte. Although the asynchronous name implies that the system is not synchronised, it can only work in practice if the transmitting and receiving terminals are accurately synchronised. This is achieved by having the data sent at standard rates, and using accurate crystal-controlled clock signals at both ends of the system.

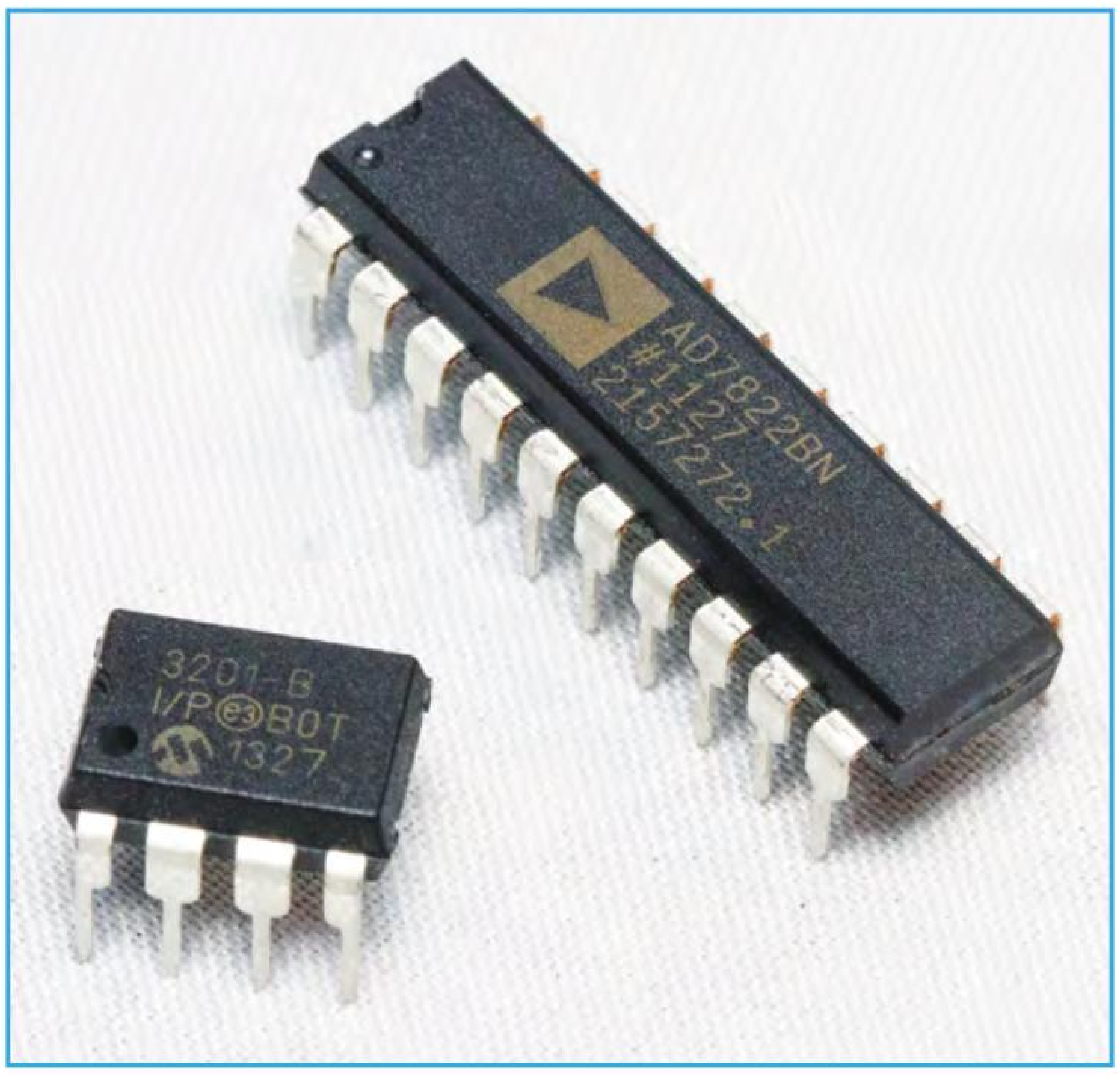


Fig.1. The 12-bit converter chip on the left requires far fewer pins than the 8-bit type on the right due to the use of serial rather than parallel interfacing

The main advantage of an asynchronous system is that in its most basic form it only requires one data line plus an earth connection in order to transfer bytes of data. A few more connections are needed in order to implement a practical synchronous serial interface, but it is simpler in other respects. In particular, it does not require accurate clock signals at both ends of the system. The clock signal can be generated by the transmitting or sending device, and an additional connecting wire is used to couple it from one to the other. In the current context, the computer is normally the controlling device, and as such it generates the clock signal.

Perfect timing

It is not necessary for the clock signal to be at a specific frequency, and it does not even matter if its frequency varies radically while each chunk of data is being transferred. The two ends of the system use the same clock signal, and must therefore remain synchronised regardless of the clock rate. If the device sending the clock signal slows down or speeds up, then the receiver will change to match it. A practical synchronous serial system requires at least one other interconnection so that the sending device can indicate to the receiving unit that the transfer of a new chunk of data has started and that it must be clocked into the shift register at the receiver.

I am talking here in terms of chunks of data rather than bytes, because a serial system of either type is not restricted to 8-bit transfers. A serial system can be designed to handle transfers having any required number of bits. Consequently, a 12-bit or 16-bit analogue converter still only requires three connecting wires plus an earth. Thus, a 12-bit serial converter chip only needs eight pins while an 8-bit parallel type has double that number, or even more.

MCP3201

The pin function diagram for the MCP3201 is shown in Fig.2. It requires a single supply in the range 2.7 to 5.5V, and the maximum current consumption is 400µA. There is no problem in running it from the 3.3V supply output of the GPIO port, and this makes it compatible with the 3.3V logic levels of this port. There are differential inputs at pins 2 and 3, but the IN– pin can be no more than 100mV above or below the Vss pin. In practice, the IN– pin is usually connected to ground and the input voltage is applied to the IN+ pin.

There is no built-in voltage reference, and an external reference potential of between 0.25V and the supply potential must be applied to pin 1. This can be a precision reference source, or for non-critical applications it can simply be connected to the positive supply rail. The full-scale input voltage is equal to the reference level used. Unusually for an analogue-to-digital converter chip, the analogue input does not have an extremely high input impedance. Consequently, where appropriate it, must be driven via a buffer amplifier.

Pin 5 is the negative chip select input, and this is held high (logic 1) under standby conditions. Bringing it low takes the chip into its active mode, and operates the integral sample-and-hold circuit at the analogue input. After two clock cycles the data output at pin 6 goes from a high impedance state to logic 0, and it stays there for the next clock cycle. This is not a proper data bit and it must be ignored by the software in the computer. The first bit of data, which is the most significant bit, is placed onto the data output

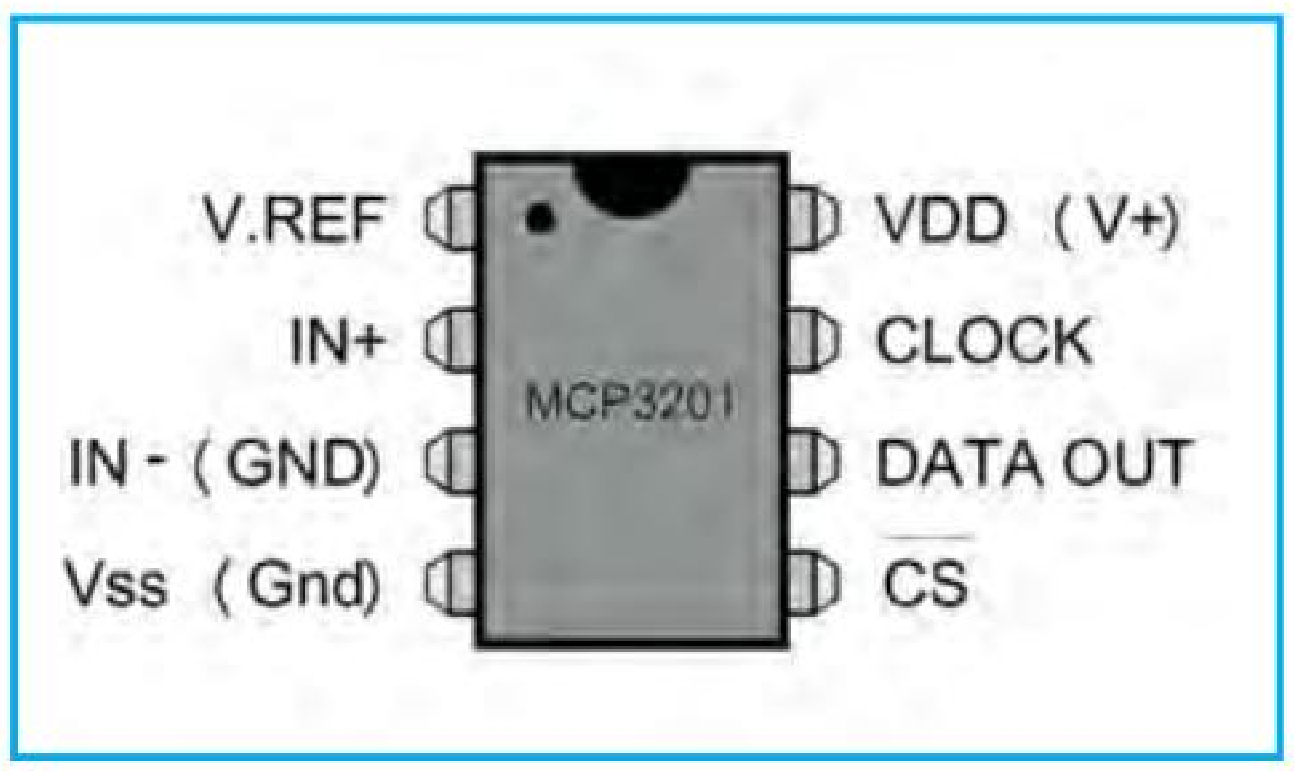


Fig.2. Connection details for the MCP3201. It has differential inputs, but in most applications the IN– pin is just connected to ground and the single input signal is applied to IN+

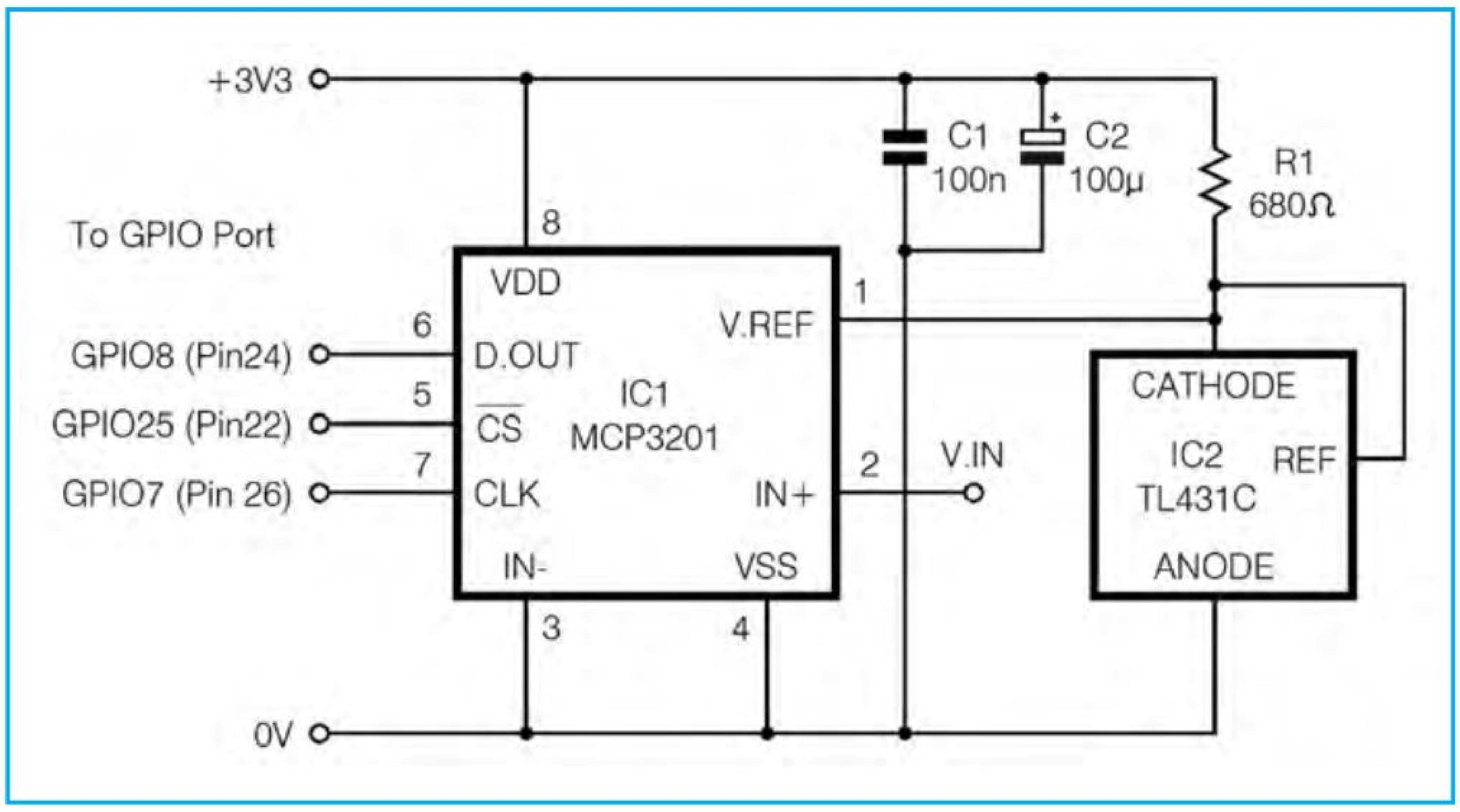


Fig.4. The circuit diagram for the 12-bit serial analogue-to-digital converter. IC2 is a shunt regulator that provides a 2.5V reference level for converter chip IC1

on the falling edge of the next clock cycle. The other eleven bits of data are placed onto the data output on the falling edges of the subsequent eleven clock cycles. Any further clock cycles are permissible, but irrelevant. Finally, the chip select input is returned to the high state. This deactivates the chip so that it is ready to start another conversion and reading cycle.

Fig.3 shows the timing diagram for the MCP3201. The chip select input is taken low in order to start the conversion and reading process, and then three clock cycles are used to initialise the converter and clock out the first bit of data onto the data output. This bit is then read by the computer, another clock pulse is produced, and the next bit of data is read. The same procedure is repeated until all twelve bits of data have been clocked out and read. To complete the process, the chip select input is returned to the high state, and the system is then ready to start the next conversion.

Of course, the computer will have read what are effectively twelve single-bit binary values, but some simple mathematics is all that is needed in order to turn these individual bits of data into the corresponding decimal value. With 12-bit resolution this is a number in the range 0 to 4095. An 8-bit converter gives a range of 0 to 255.

Converter circuit

Fig.4 shows the circuit diagram for a basic 12-bit analogue-to-digital converter for use with the GPIO port of a Raspberry Pi. The chip select and clock inputs of the converter are fed from GPIO25 and GPIO7 respectively, and these must be set as outputs. GPIO8 is set as an input and is used to read the bits of data from IC1.

The reference voltage is provided by a TLC431C precision adjustable voltage reference (IC2). This is a shunt regulator that is used in conjunction with a discrete load resistor (R1), in essentially the same way as a Zener diode. However, it provides much greater accuracy and stability than a Zener diode. The output can be adjusted using two resistors as a potential divider to feed a portion of the output voltage to the REF input. The output voltage range is 2.5 to 36V, but in this case the basic 2.5V figure is all that is needed. This is obtained by simply connecting the REF input directly to the CATHODE terminal.

Noise abatement

With a full-scale potential of 2.5V the converter has a resolution of approximately 610µV. The downside to such a high degree of resolution is that the system is vulnerable to problems with noise and the slight instability in readings that this can cause. Those with memories that go back to the BBC Model B computer and its in-built 12-bit analogue-to-digital converter will remember the difficulties associated with achieving anything approaching true 12-bit accuracy.

The manufacturer's data for the MCP3201 makes it clear that supply decoupling is not optional, and that good decoupling is needed in order to avoid noise problems. It also recommends that the decoupling capacitor should be connected as close to the chip as possible. I found that it was best to use two decoupling capacitors (C1 and C2), which should both be good quality components. Due care should be taken with the component layout of the circuit, including the circuitry that drives the converter. There is no point in striving to produce a converter that is reasonably free from noise problems and then feeding it with a noise-infested signal.

The converter and voltage reference circuits are both powered from the 3.3V supply available from the GPIO port. The total current consumption of the circuit should be no more than about 2mA, which is well within the maximum current rating of this supply. Connection details for the TLC431C are shown in Fig.5, which is a top view. The MC3201 used for IC1 is an MOS device and it therefore requires the standard anti-static handling precautions.

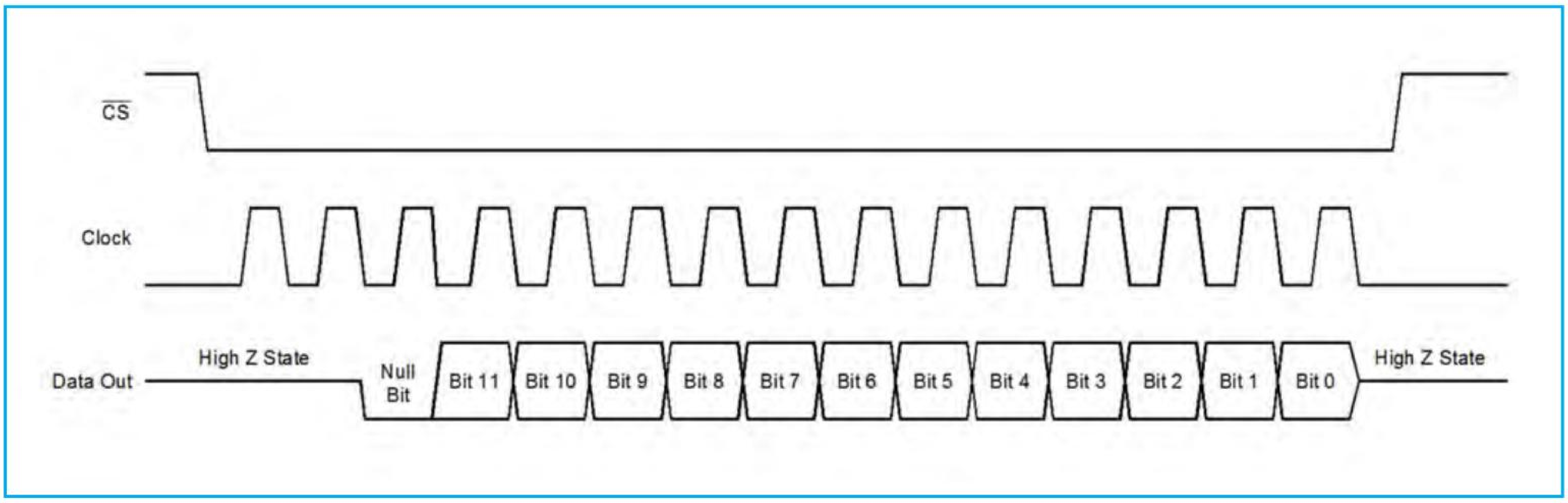


Fig.3. The timing diagram for the MCP3201. The first bit of data becomes available on the falling edge of the third clock cycle

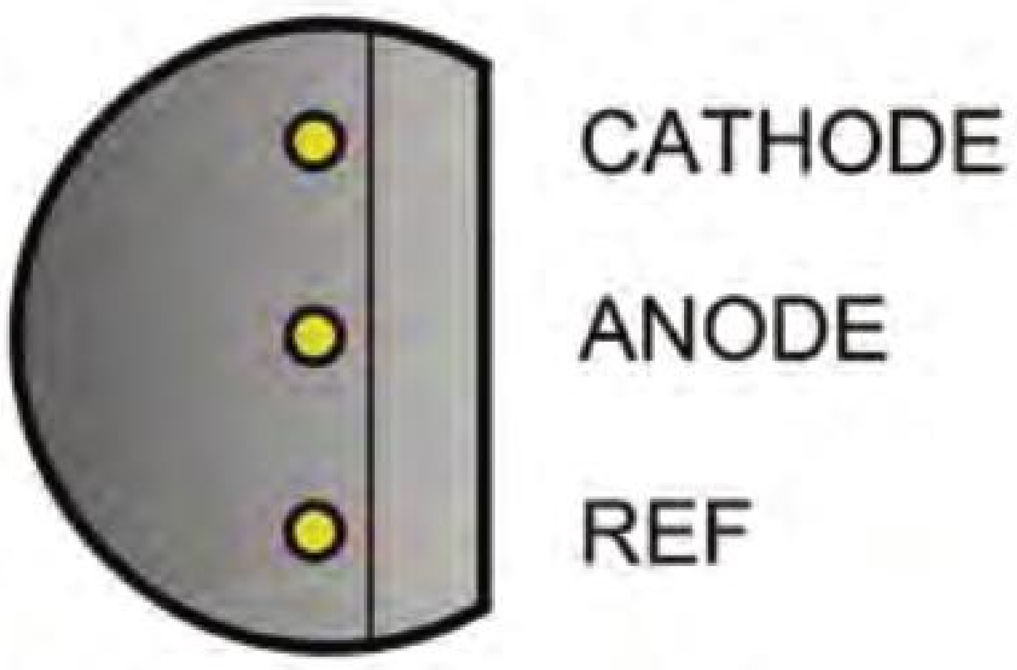


Fig.5. Connection details for the TL431C regulator. Note that this is a top view and not a transistor-style base view

Software

Although the program I originally used with the converter worked quite well, on close examination it was found to be slightly less than totally successful. On the face of it, the program worked perfectly well, but it did not quite deliver the full-scale value of 4095 with the analogue input connected to the reference source. Also, higher readings were less stable than they might have been. This was due to the program operating too slowly. The manufacturer's data recommends that the clock frequency should be at least 10kHz, and this is due to the sample-and-hold circuit at the input of the converter chip. Lower frequencies can result in the conversion and reading process taking so long that the charge voltage on this capacitor sags slightly while the reading is being taken.

The original program worked by converting the binary data into the equivalent decimal value during the reading process, with the decimal value being updated immediately after reading each bit. In the final version, which is shown in Listing 1, a slightly different approach is taken. As each bit of data is read, its contents are placed in a variable. A different variable is used for each bit, and these are 'B0' to 'B11'. The twelve bits of data are then converted into the equivalent decimal value once the reading and conversion process has been completed. This makes the program somewhat longer, but it simplifies and speeds up the reading of each conversion. Anyway, this had the desired result and enabled the full-scale value of 4095 to be achieved, together with more stable readings.

With proper decoupling there was not a significant noise problem with the converter. However, even with the converter working well there could be problems with noise on the input signal. This is a common problem when using a resolution of 12-bits and beyond, and it is often due to inherent noise in the signal source. The program 'smoothes' noise by using a `while… loop` to take ten readings in rapid succession, and then displaying an average of these readings. It will not be necessary to bother with averaging in all applications, but it can be very effective when noise will otherwise cause jittery readings.

Listing 1

```
import RPi.GPIO as GPIO
import time
GPIO.setmode(GPIO.BOARD)
GPIO.setwarnings(False)
GPIO.setup(22, GPIO.OUT)
GPIO.setup(24, GPIO.IN)
GPIO.setup(26, GPIO.OUT)
GPIO.output(22, GPIO.HIGH)
GPIO.output(26, GPIO.LOW)
Readings = 0
Average = 0

while(Readings < 10):
    dataword = 0
    GPIO.output(22, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B11 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B10 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B9 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B8 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B7 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B6 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B5 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B4 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B3 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B2 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B1 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(26, GPIO.HIGH)
    B0 = GPIO.input(24)
    GPIO.output(26, GPIO.LOW)
    GPIO.output(22, GPIO.HIGH)
    if B11:
       dataword = dataword + 2048
    if B10:
       dataword = dataword + 1024
    if B9:
       dataword = dataword + 512
    if B8:
       dataword = dataword + 256
    if B7:
       dataword = dataword + 128
    if B6:
       dataword = dataword + 64
    if B5:
       dataword = dataword + 32
    if B4:
       dataword = dataword + 16
    if B3:
       dataword = dataword + 8
    if B2:
       dataword = dataword + 4
    if B1:
       dataword = dataword + 2
    if B7:
       dataword = dataword + 1
    Average = Average + dataword
    Readings = Readings + 1

print (Average/10)
GPIO.cleanup()
print ("Finished")
```

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AUDIO OUT

By Jake Rothman

Test-bench amplifier – Part 3

Thump prevention

Annoying noise on powering up and turning off plague many audio circuits and deserves a full article in its own right. The mechanisms are transient, complex and unpredictable. The solutions are often unexpected and experimentally derived. Most designers avoid the issue by using relays. These are unreliable, expensive, power consuming and make a click themselves. With this circuit, turn-on thumps were found to be prevented by slowly turning on the negative rail to the driver stage. I discovered this accidently by putting in a negative-rail decoupling capacitor that was too large. To minimise space, a MOSFET source follower with a small tantalum capacitor was used to generate the delay and provide good smoothing. This part of the circuit is shown in Fig.9 and 10. The small diode discharges the capacitor on turn-off, so the delay is always present.

The thump from the op amp input stage is removed by sizing its

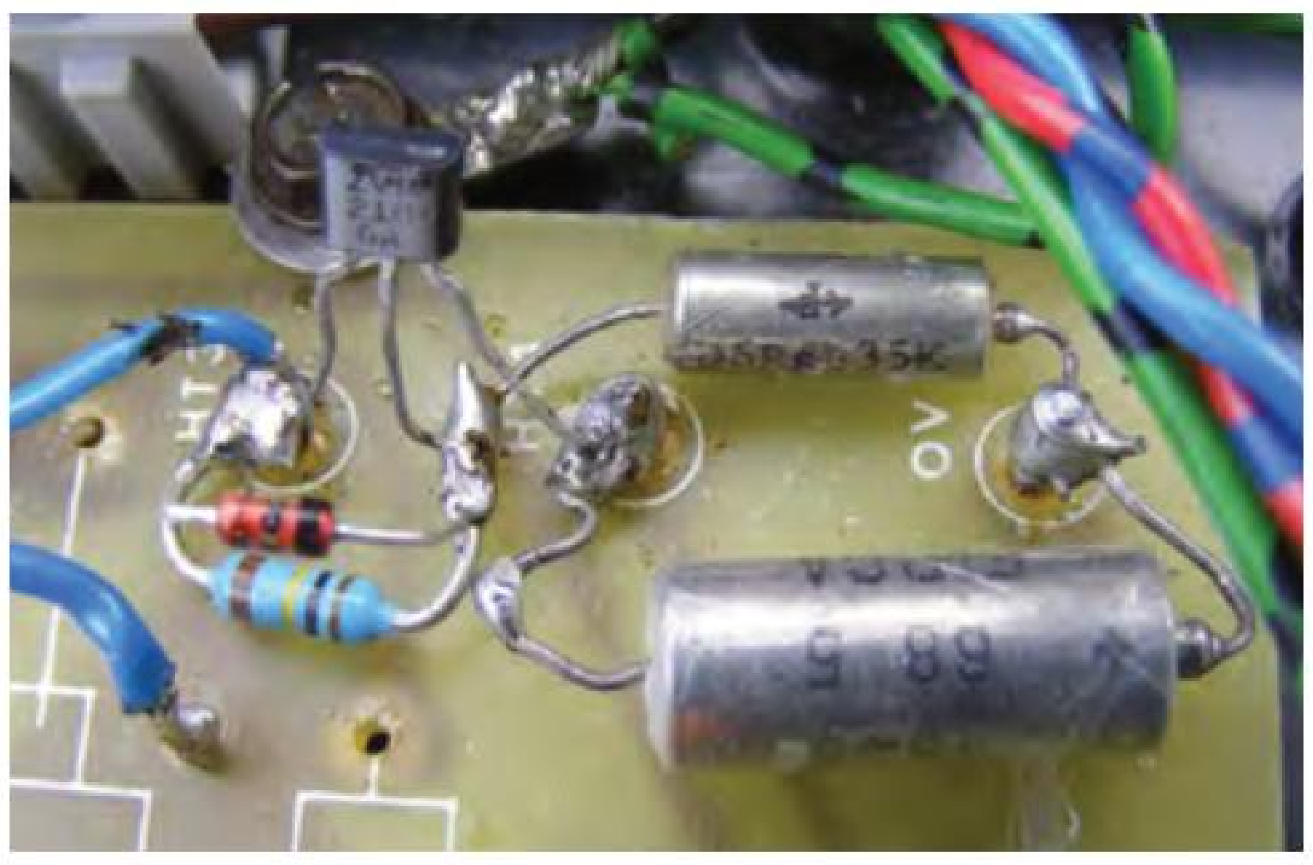
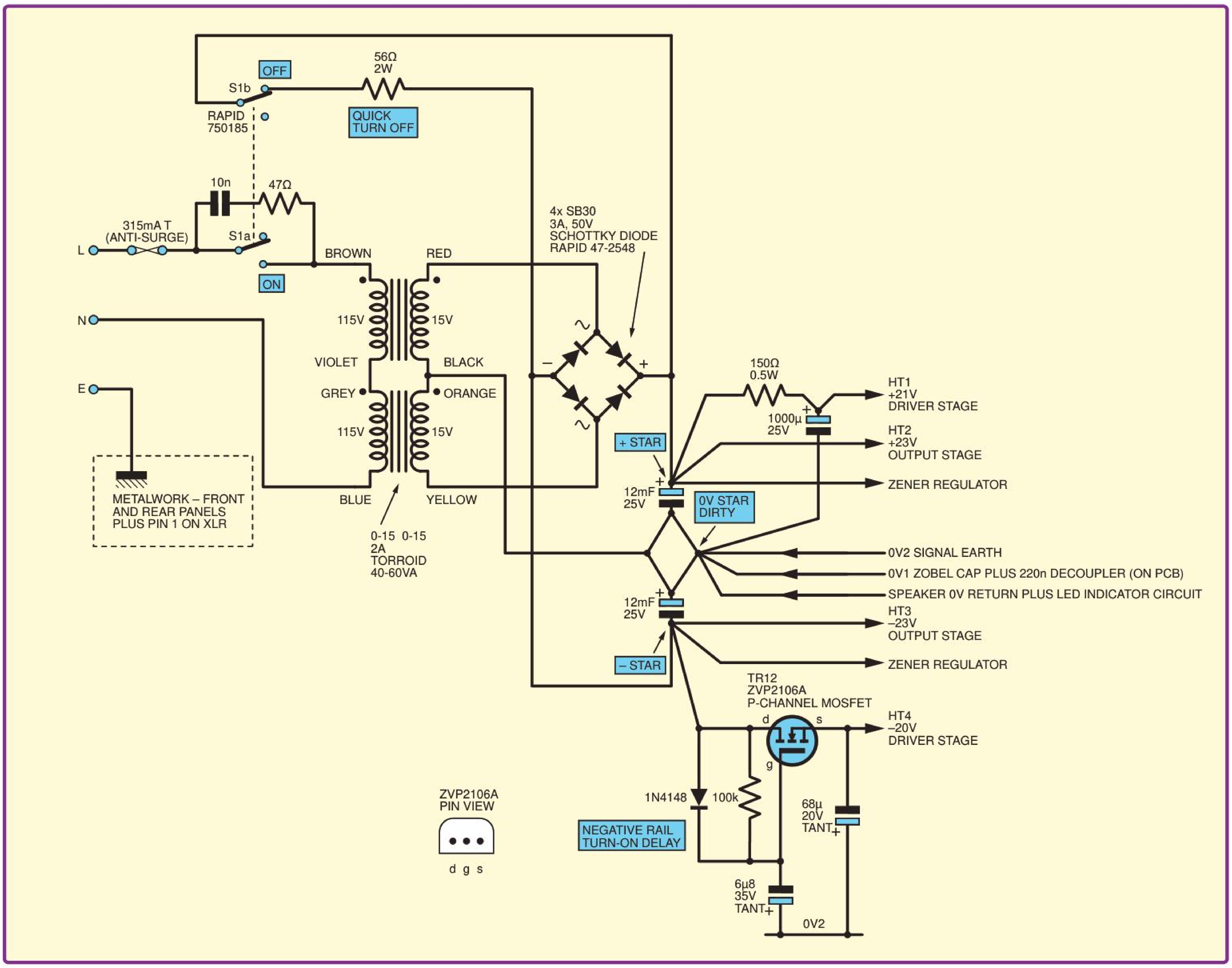


Fig.9. The de-thump circuit using a P-channel MOSFET to slowly ramp up the driver-stage current.



OFF
S1b
56Ω
2W
RAPID
750185
QUICK
TURN OFF
10n
47Ω
315mA T
(ANTI-SURGE)
S1a
L
BROWN
RED
ON
4x SB30
3A, 50V
SCHOTTKY DIODE
RAPID 47-2548
N
115V
15V
VIOLET
BLACK
E
GREY
ORANGE
115V
15V
–
+
~
~
METALWORK – FRONT
AND REAR PANELS
PLUS PIN 1 ON XLR
BLUE
YELLOW
0-15 0-15
2A
TORROID
40-60VA
150Ω
0.5W
HT1
+21V
DRIVER STAGE
1000µ
25V
+ STAR
HT2
+23V
OUTPUT STAGE
ZENER REGULATOR
12mF
25V
0V STAR
DIRTY
0V2 SIGNAL EARTH
0V1 ZOBEL CAP PLUS 220n DECOUPLER (ON PCB)
SPEAKER 0V RETURN PLUS LED INDICATOR CIRCUIT
12mF
25V
HT3
–23V
OUTPUT STAGE
– STAR
ZENER REGULATOR
TR12
ZVP2106A
P-CHANNEL MOSFET
d
s
g
HT4
–20V
DRIVER STAGE
ZVP2106A
PIN VIEW
d g s
1N4148
100k
68µ
20V
TANT
NEGATIVE RAIL
TURN-ON DELAY
6µ8
35V
TANT
0V2

Fig.10. The amplifier power supply – note the complicated noding around the main smoothing capacitors. All audio systems have three 'grounds': safety/mains/chassis, high-current/dirty (0V1) and signal/reference (0V2). Pin 1 on XLR connectors is always connected to chassis to prevent circulating earth currents impinging on the signal ground according to the AES (Audio Engineering Society) convention

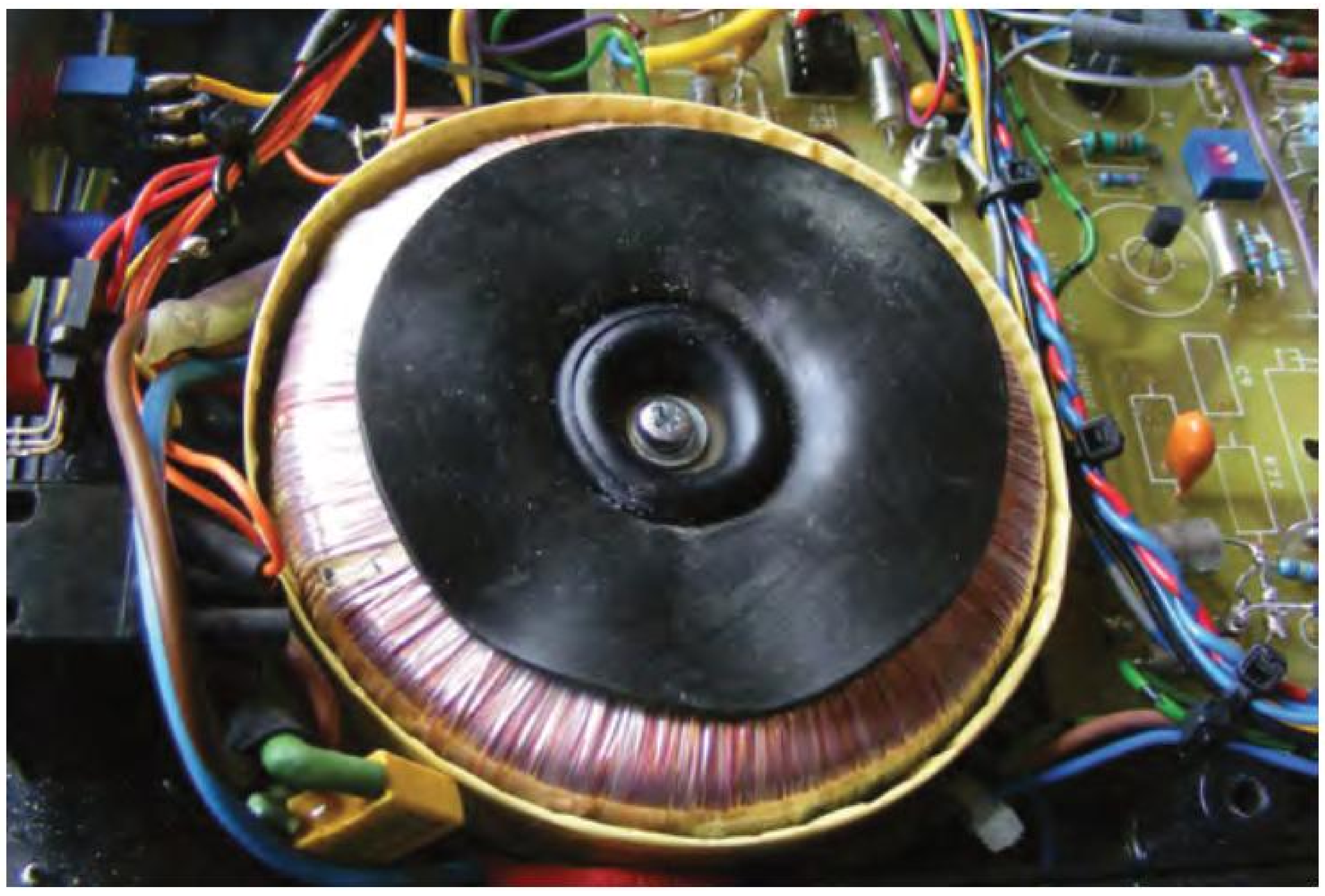


Fig.11. Surrounding a torroidal transformer with an insulated steel band reduces magnetic emissions

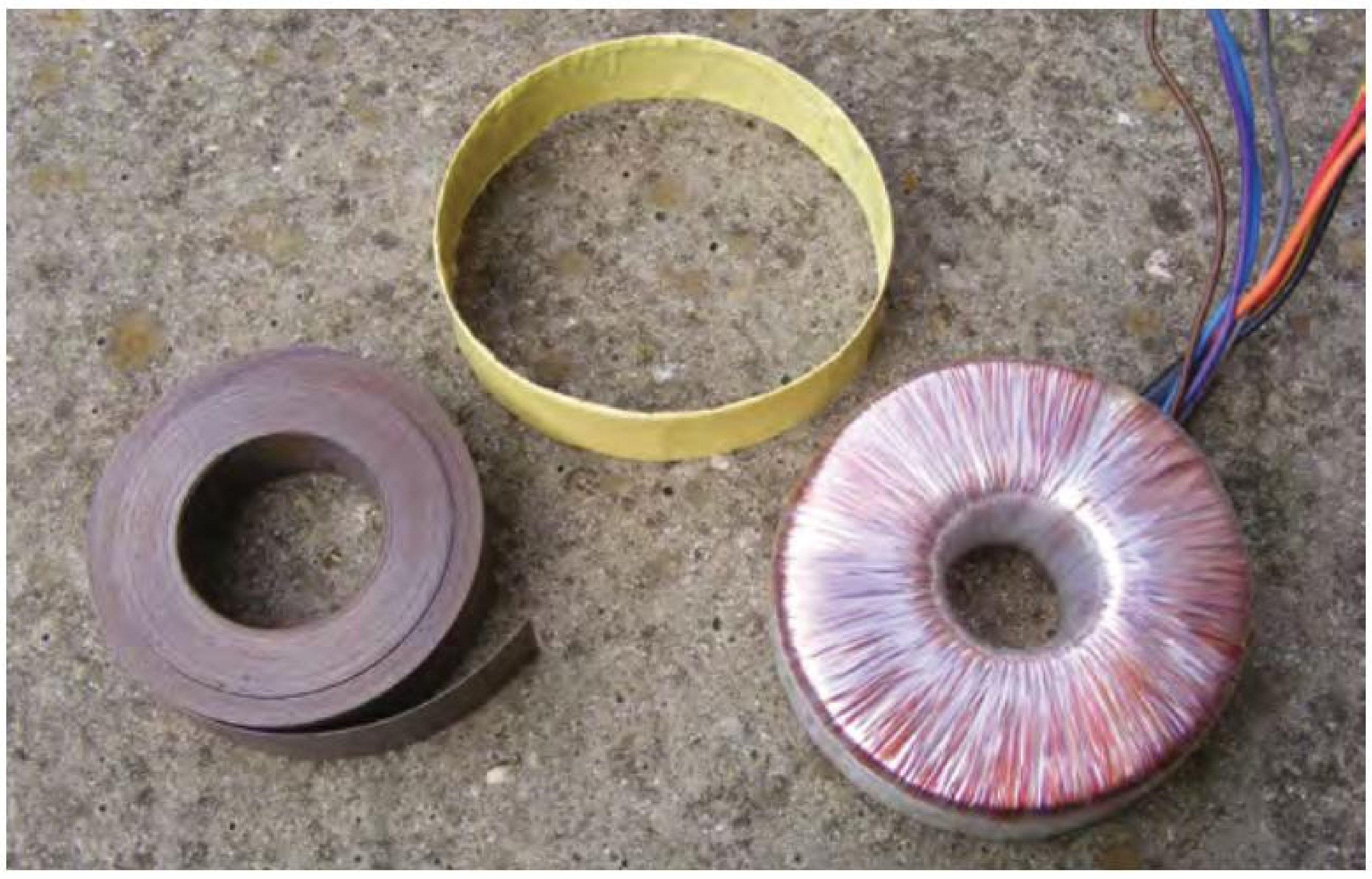


Fig.12. An old toroid core (left) provides a useful source of grain-oriented steel band for screening

decoupling capacitor so that the circuit remained powered for just the right time after turn-off. A 6µ8 35V cap did the job. Also, the current sink, driver stage power-rail and bias transistor bypass capacitors all have to be the correct value to prevent thumps. Naturally, I use solid tantalum types for all the small values for long-term stability.

Low-emission power supply

The use of a torroidal transformer helps to reduce magnetic fields. One of my 'secret' tricks to gain a further reduction of around 10dB at low frequencies, is to surround the transformer with an insulated steel strip, as shown in Fig.11. The strip is unwound from the core of a burnt out torroidal transformer (see Fig.12). Using copper, as in the 'bellyband' strap applied to laminated transformers doesn't work. Schottky rectifiers reduce switching noise and voltage drop, giving 2V more from the 15-0-15V transformer used – this gave an extra 1.4W output and less heat.

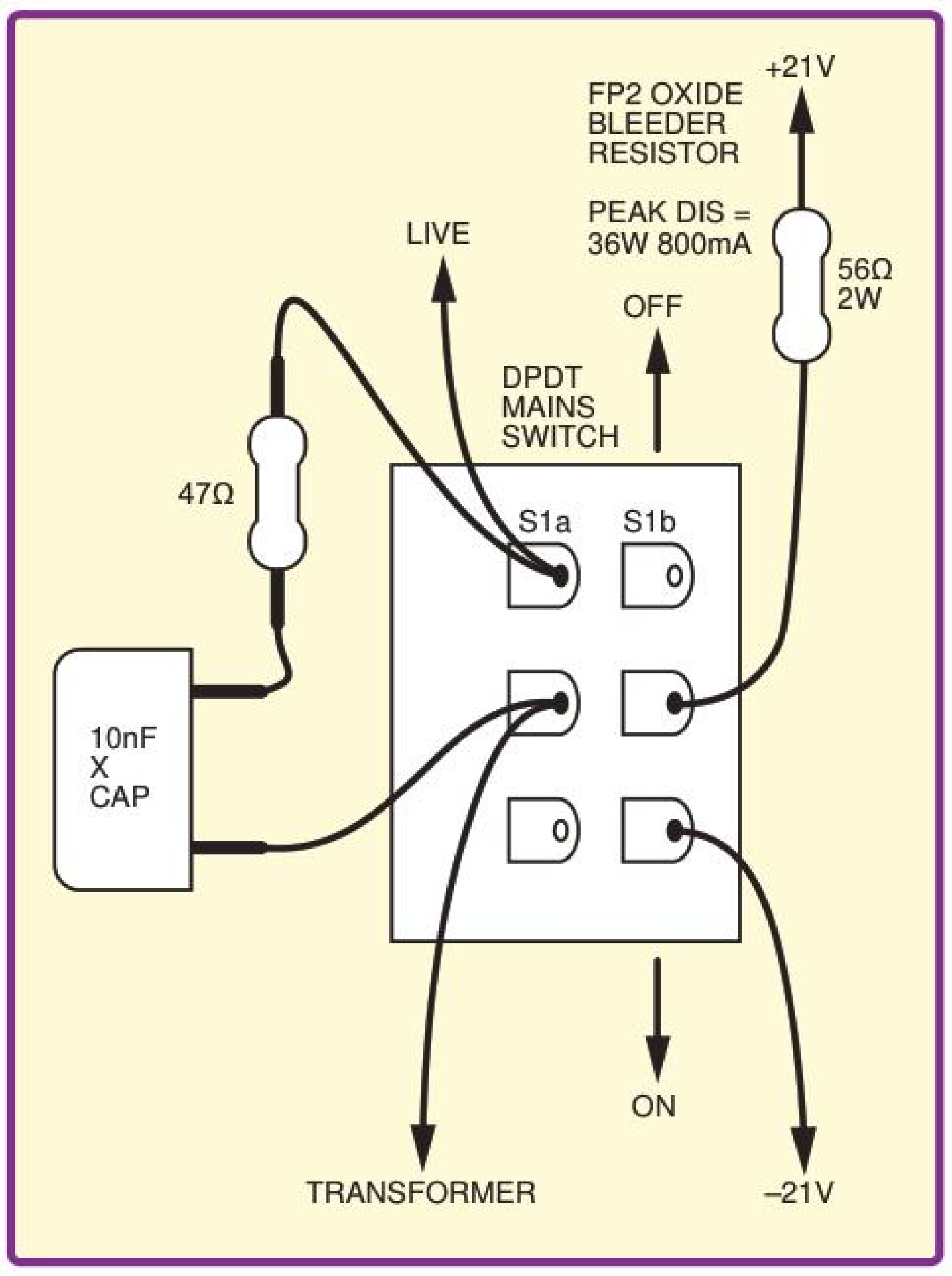


Fig.13. Wiring a DPDT mains switch to discharge the power rails when turned off

Quick turn-off

It is very irritating if an amplifier 'carries on' for a while after it has been turned off, especially if there is a horrid noise while testing something. In this design, the power rails are quickly discharged by a high-power resistor connected across them when the switch is flipped to the off position. The wiring for this arrangement is shown in Fig.13. There is a snubber network wired across the mains

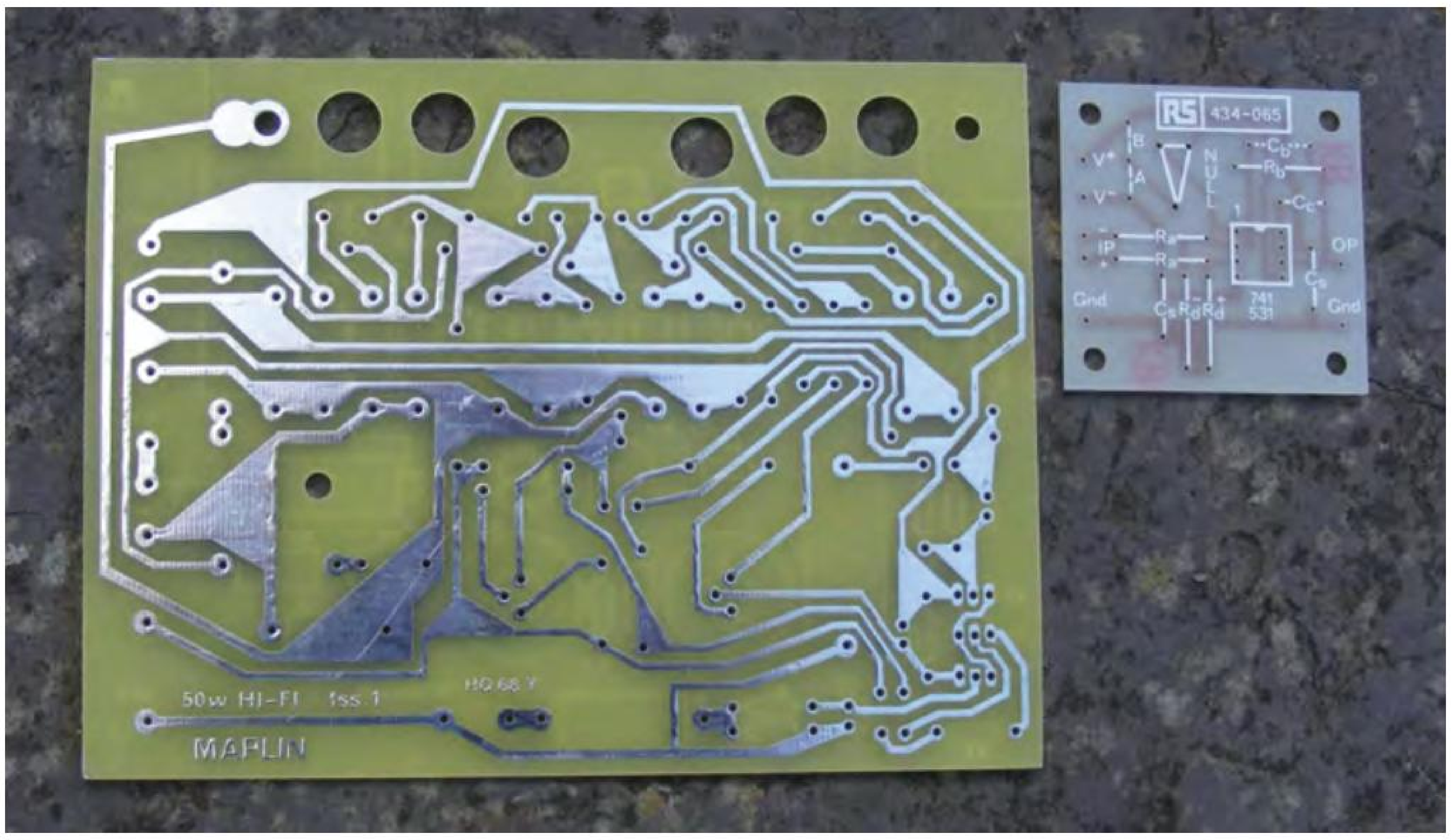


Fig.14. The PCBs used in the amplifier

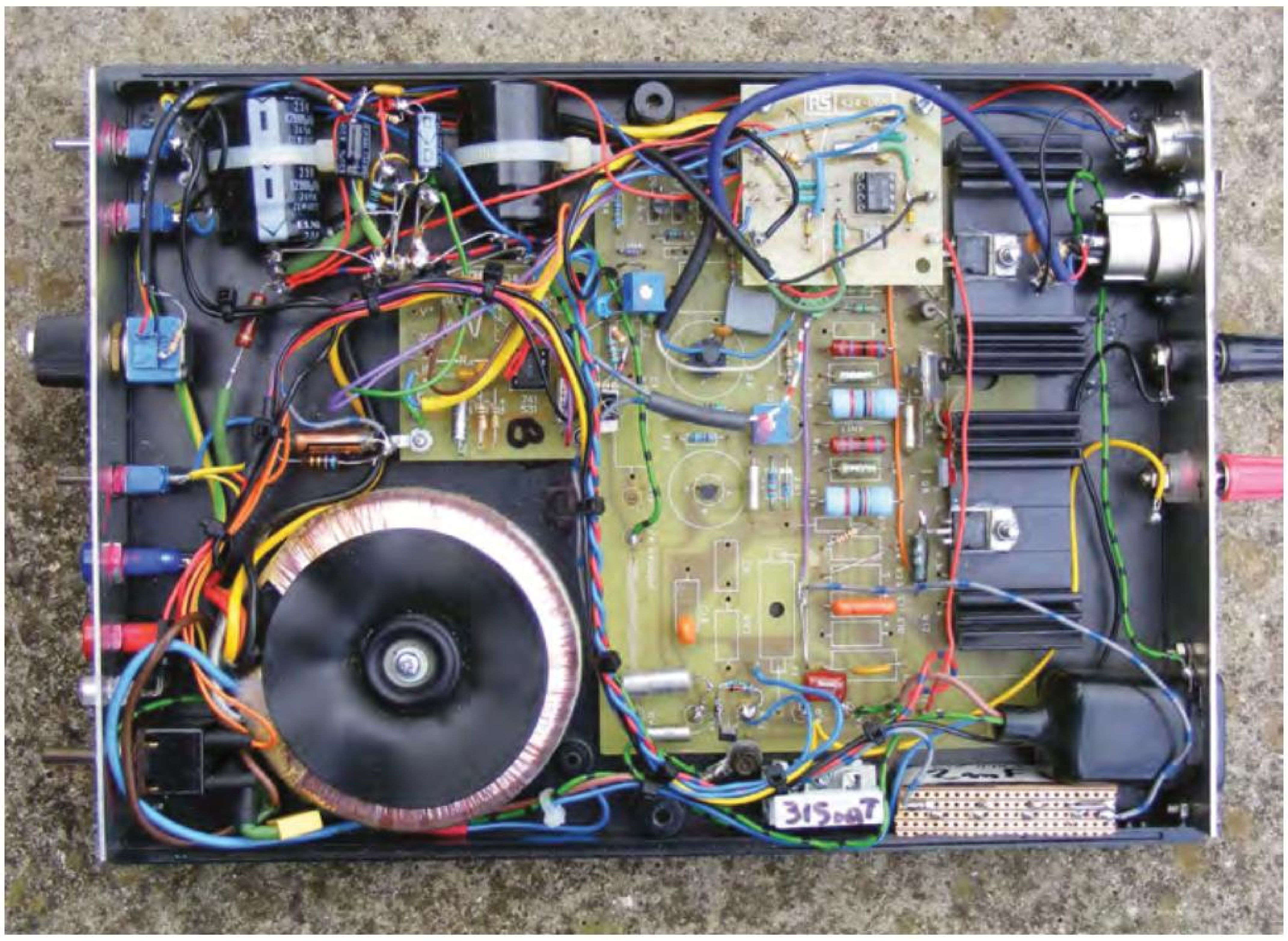


Fig.15. Internal view of the test-bench amplifier – one day I'll get it all on one PCB!

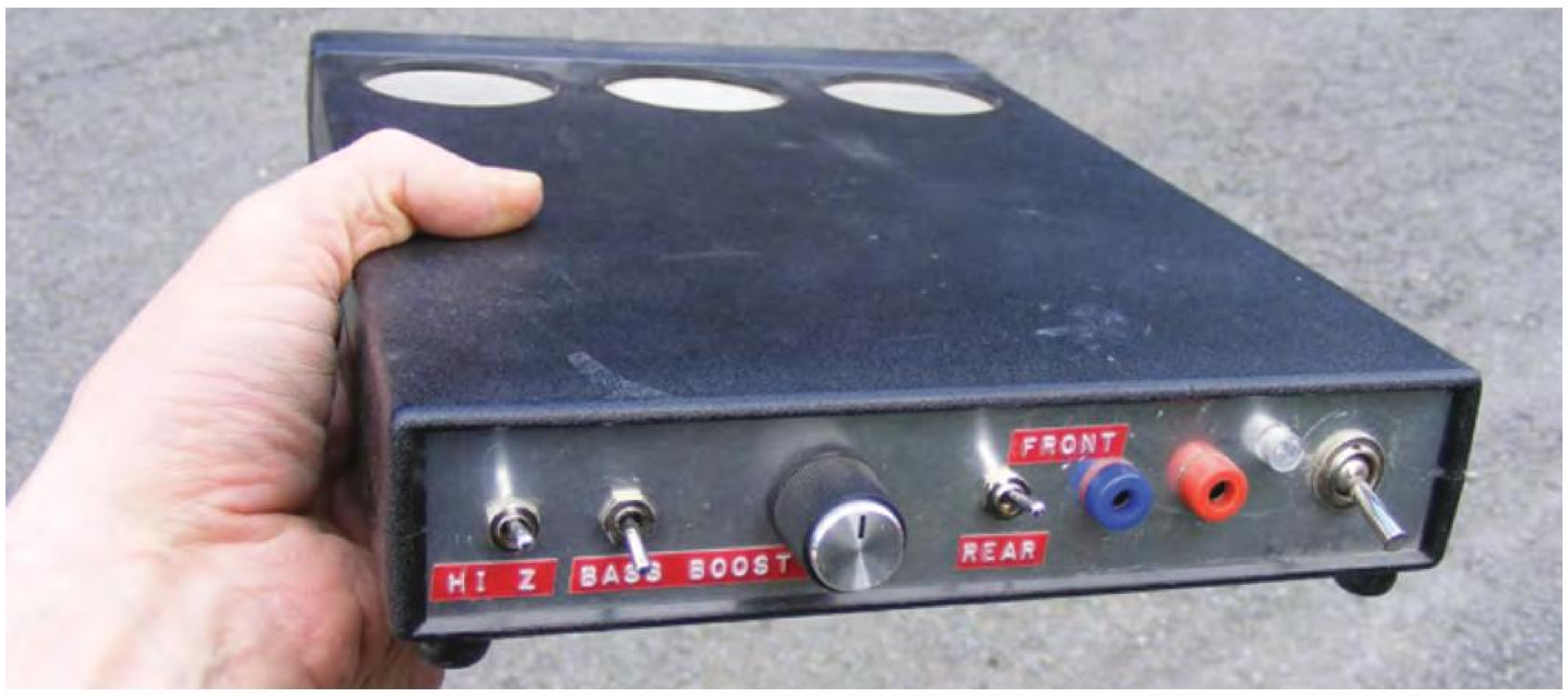


Fig.16. Finished test-bench amplifier with speaker output switchable between front and rear sockets

section to prevent an inductive 'crack' on turn-off.

Construction

The main board is a long-discontinued Maplin 50W amp HQ 68Y PCB with altered component positions, a few cut tracks and links, so no layout is given here, just the schematics. The input stage and overload indicator are constructed on RS 741 op amp PCBs. Both these PCBs are shown in Fig.14.

The power supply circuit is shown in Fig.10. Note the special noding to avoid the capacitor charging pulses coupling to the power rails. Other nodes also prevent the half-wave signal currents from the output stage entering the reference ground 0V2 and the low-power rails. This layout is difficult to achieve with the requisite low resistance on a single-sided PCB so it is hard-wired. Simple Zener regulation suffices for the input op amp, with diode decoupling for the LED driver.

The unit is mono and two are needed for stereo. In development work, usually only one channel is needed. Two separate amplifiers with ground lifting and individual power supplies prevent earth loops, which often occur in stereo test-gear lash-ups. A compact Hammond 1598 case from Farnell measuring 280mm deep by 200mm wide and 40mm high is used to accommodate the amplifier and the well-stuffed interior is shown in Fig.15. The front panel is shown in Fig.16; note the provision of switchable speaker sockets. The rear panel (Fig.17) has a special 4-pin DIN socket giving access to the power rails via 220Ω current-limiting resistors.

Note that all the parts described in my columns are bought in bulk for manufacturing and education; I can usually supply them relatively cheaply. I often quote Rapid order codes since they are the cheapest mainstream UK distributor. Please contact me if you need anything:

Email: jacob.rothman@homecall.co.uk
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Who would have thought a little test bench amp could be so complicated? However, it did generate some new circuits and in turn spawned a thump-free capacitor-coupled Hi-Fi integrated pre/power amp needing only a single rail power supply, which I'll discuss next month. After that I'll give some audio insiders' design techniques for small Hi-Fi speakers, culminating in a top-quality system suitable for test bench use.

Top audio tip!

Before I forget – remember while sniffing that solder smoke, buying a new fume filter is less hassle than a lung transplant!

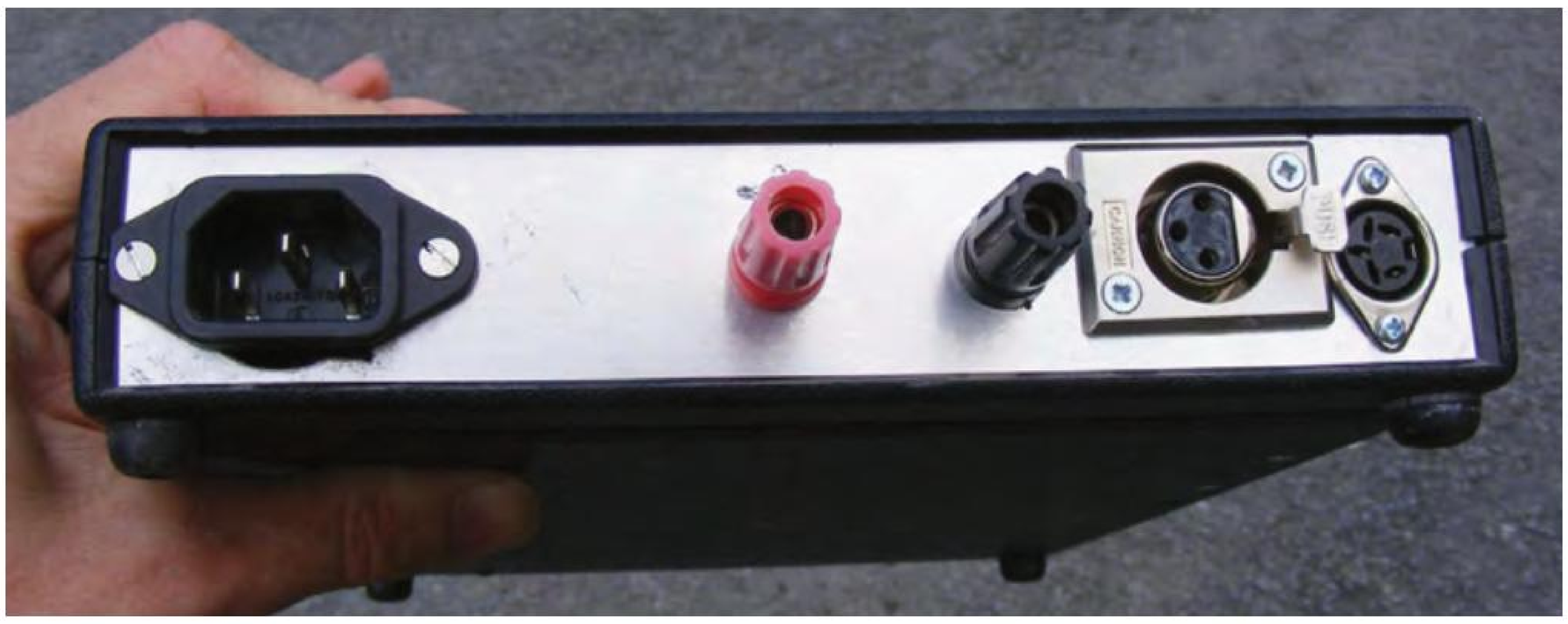

Fig.17. Rear of the amplifier

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Max's Cool Beans

By Max The Magnificent

Mastering meters – Part 2

In my previous column, I mentioned that I like using analogue meters for my hobby projects because they offer a certain sense of style. Furthermore, I'm really into the 'Steampunk' look and feel, so I prefer to use the antique variety that I pick up at electronic flea markets for just a few dollars each.

Just to give you a sense of what I'm talking about, take a look at Fig.1, which shows the meters I'm using to implement my Vetinari Clock project. The large 'Hours' meter has a 4.5-inch external diameter; the medium-sized 'Minutes' and 'Seconds' meters are both 3.5-inch in diameter; and the small 'Tick-Tock' (metronome-style) meter is 2.5-inch in diameter. I picked up all of these meters at my local Huntsville Hamfest last August (**http://ubm.io/1vHyKah**).

As we will see, there are all sorts of things to consider with regard to using these little beauties from yesteryear, not the least of which is how we set about creating the required faceplates (you must admit they look mega-cool), but let's not get ahead of ourselves.

Choosing your meter

OK, so let's suppose we are 'out-and-about' at a Hamfest. It may be that we have a project in mind (like my Vetinari Clock) and already have an idea as to the meter(s) we're looking for. Alternatively, we may just be looking for anything 'tasty' on the basis that there will always be future projects that will benefit from one or more analogue meters.

So we grab a likely candidate. The first thing to look for is if this meter is intended to display a direct current (DC) or alternating current (AC) value. In reality, AC meters are just DC meters with some extra 'fiddly bits', but it's a lot easier to work with DC meters, so that's what we'll focus on here (which is another way to say that you should put the AC meter down and continue looking).

The next test is to check that the meter's needle is somewhere close to the zero position, then move the meter gently back and forth and observe the needle move smoothly (it doesn't have to move far, at this stage we're just trying to demonstrate that it does move).

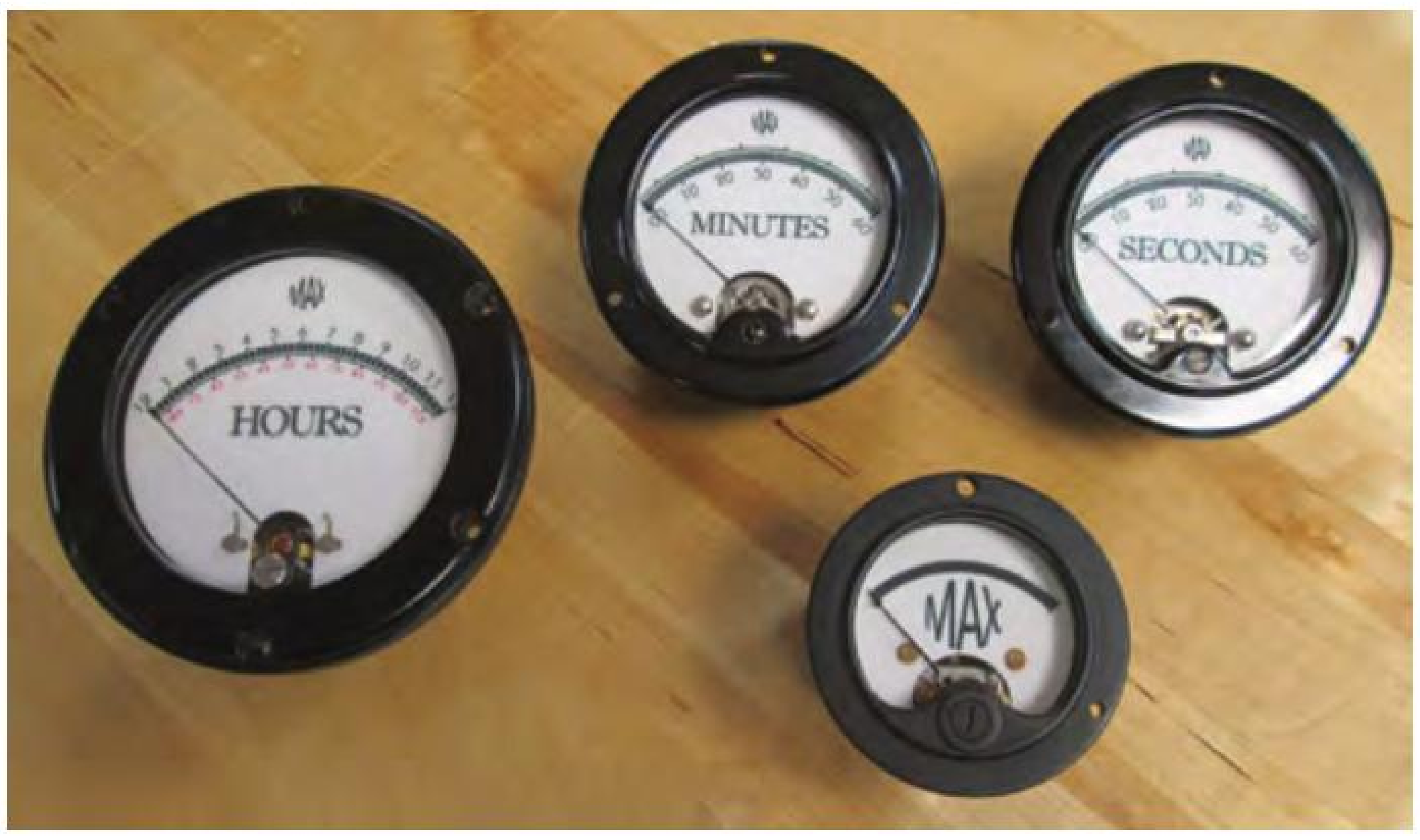

Fig.1 The meters that will provide the main display for Max's Vetinari Clock

Speaking of this, you may have wondered why you often see a piece of wire connecting the two terminals at the back of a meter (if there isn't one on a meter you purchase at a flea market, you should add one yourself). The purpose of this wire is to dampen down the motion of the needle when you are transporting the meter, thereby preventing it from bashing up against the end-stop. The way this works is as follows. When you apply a voltage/current to the meter, this causes the needle to move. Similarly, when you are transporting the meter and you jerk it, the movement of the needle generates a current. The term counter-electromotive force (counter-EMF or CEMF) – which we used to call 'back EMF' when I was a lad – refers to the voltage, or electromotive force, that 'pushes' against the current that induces it. By connecting a wire across the meter's terminals, you allow the current generated by the moving needle to flow, thereby generating a CEMF/back-EMF that dampens the needle's motion.

Any meter you want, providing it's a current meter

In the case of quantum mechanics, the Heisenberg uncertainty principle states that the more precisely the position of an atomic particle is determined, the less precisely its momentum can be known, and vice versa. To put this another way, the act of observing something affects (modifies) the thing being observed. The same principle applies with analogue meters – when we introduce them into a system, they perturb that system in some way, so the trick is to arrange things such that the effect of the meter on the system is as small as possible.

Now, do remeber that irrespective of what a meter shows on its faceplate – which can be anything from volts, current, or resistance to megawatts, kilojoules, or gigawallabies – at the end of the day, at their heart, all of these meters are current meters.

Shunt and series resistance

In the case of a meter that is actually intended to reflect a current value, this will eventually be connected in series with whatever signal it's measuring. Since we wish to minimise the meter's effect on the circuit, we wish its resistance to be as low as possible (taking everything into account, such as the sensitivity of the meter), so we will introduce a shunt (bypass) resistor across the meter's terminals, as illustrated in Fig.2(a).

By comparison, in the case of a meter that is intended to reflect a voltage value, this will eventually be connected in parallel with whatever signal it's measuring. In this case, in order to minimise the meter's effect on the circuit, we need it to have as high a resistance as possible (taking everything into account, such as the sensitivity of the meter), so we will introduce a series resistor as illustrated in Fig.2(b).

Now, Fig.2 shows the shunt and series resistors as being connected outside of the meter, but this was just for ease of representation; oftentimes, these resistors are mounted inside the meter's case (sometimes the shunt resistors look like a piece of wire). Having said this, with regard to the antique analogue meters we pick up at flea markets, we have no idea how they were originally deployed, and they may well have had external series or shunt resistors wired up in the cabinet containing the meter.

The bottom line is that the first thing I do when I start working on these old meters is to remove any and all external and internal series and shunt resistors, so all that's left is the meter's coil. Now, it's important to note that these meters are sealed units. Generally speaking, it was not intended for anyone to go inside them, so you have to be very careful here. The really important thing is to make sure we are working in as clean an environment as possible with as little dust and other contaminants as we can manage.

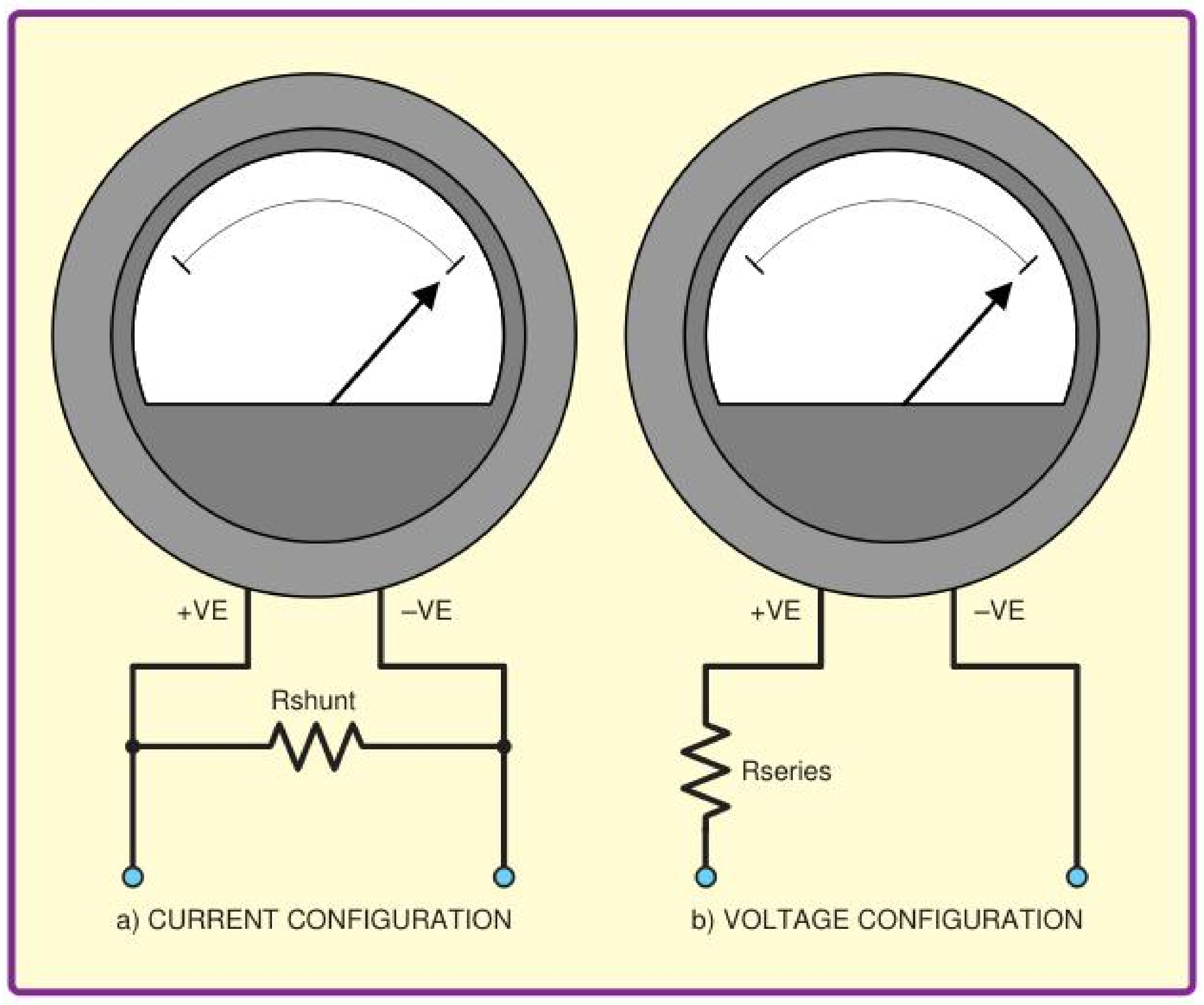

Fig.2 Shunt and series resistors

Next month!

Once we've removed any shunt and series resistors and reassembled our meters, the real fun begins. In next month's column, we'll talk about how we connect these little beauties up to our microcontroller (we'll be using a more sophisticated setup than was discussed in my previous column). Also, we'll be talking about how we create and install new faceplates that complement the project in hand. Until then, have a good one!

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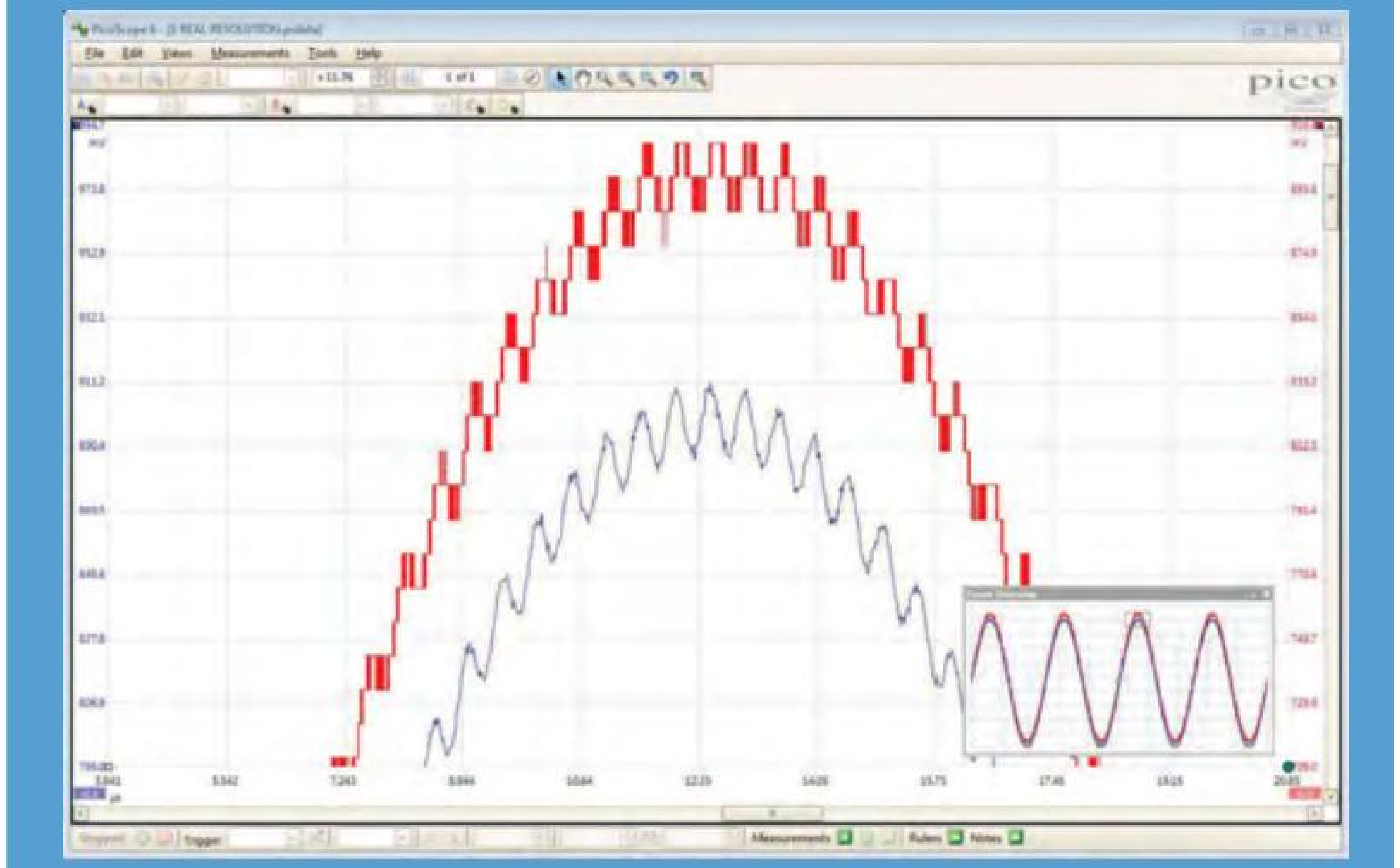

The top waveform in the screenshot, captured with 8 bits resolution and zoomed in by 64x shows up the limitations of 8–bit resolution. The same signal captured with PicoScope set to 12–bit resolution shows characteristics of the signal that were invisible in 8–bit mode. All selectable in the same scope.

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CIRCUIT SURGERY

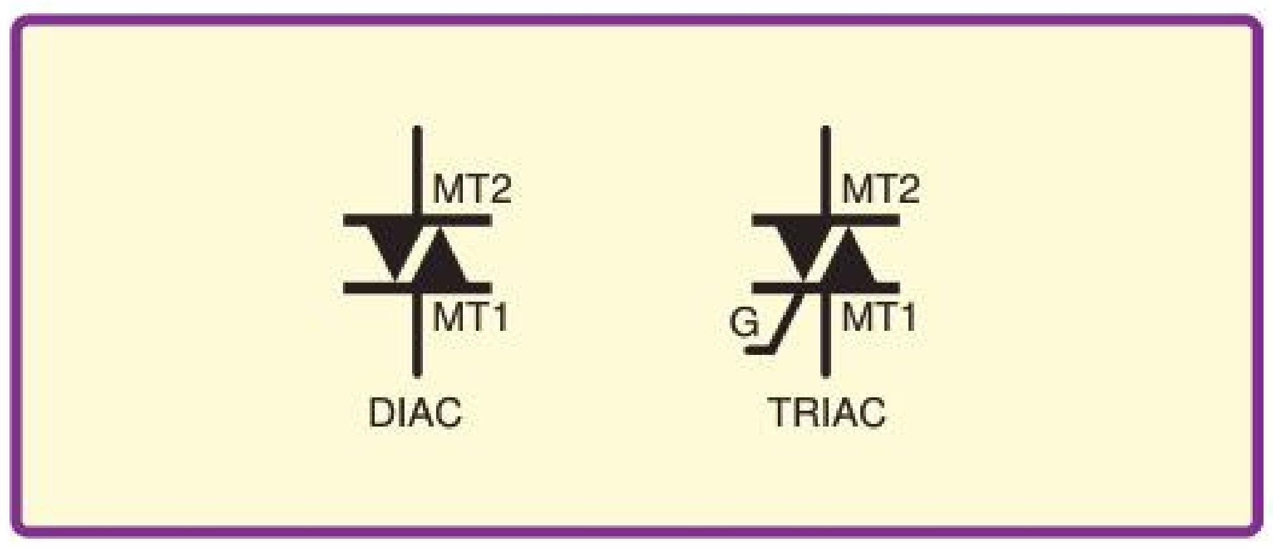
REGULAR CLINIC

BY IAN BELL

Triacs correction

We received an email from Chris Hinchcliffe pointing out an error in last month's *Circuit Surgery*.

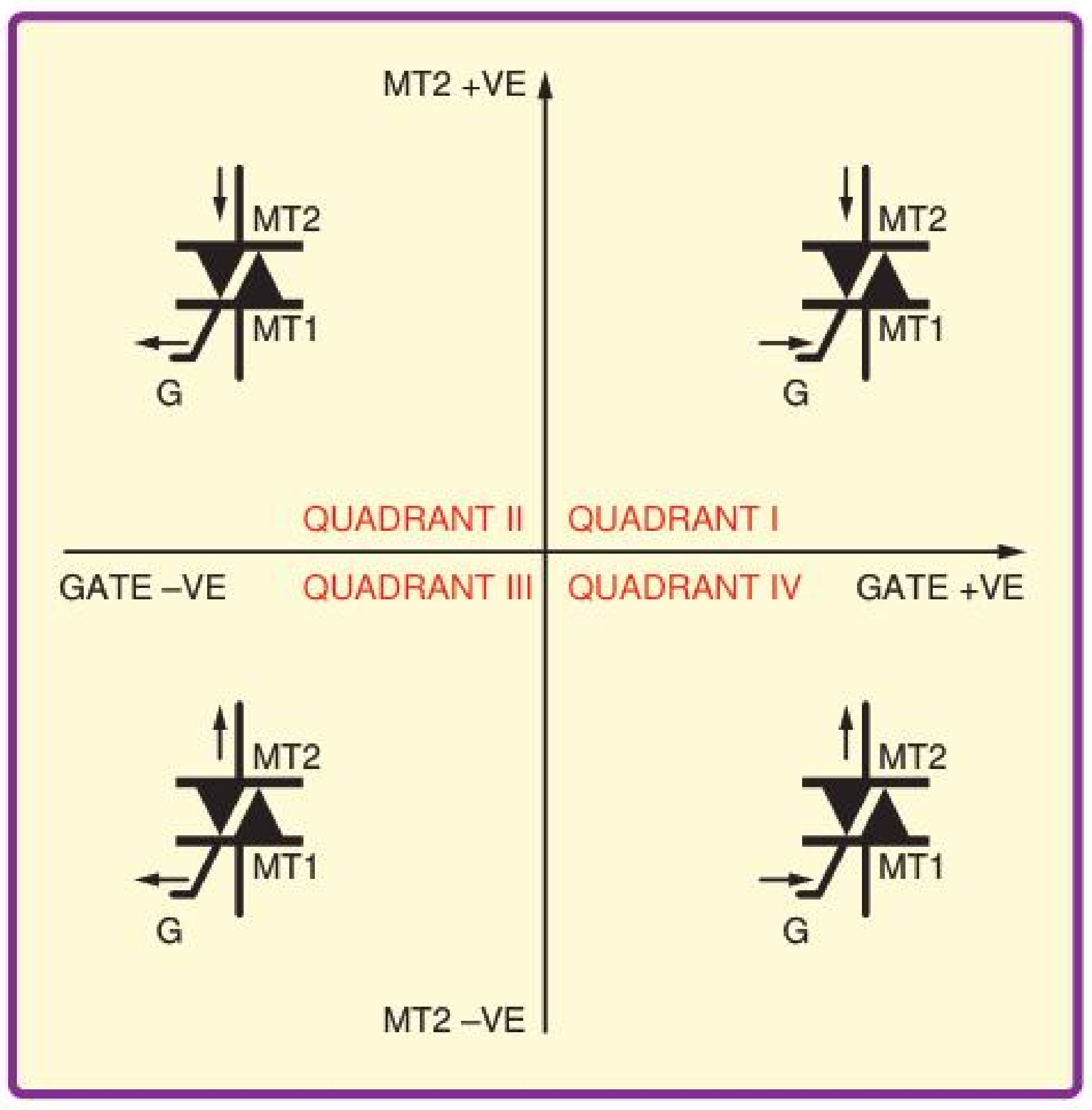
Another great article in Janaury's EPE*, this time on triacs by Ian Bell. I do have a query about the graph in Fig.4, which I think is incorrect (if I understand it correctly). I'm under the impression that the top two triac symbols on the graph should be swapped over with the bottom two. The graph's axis labels are correct. The text corresponds to what I think is the incorrect graph illustrated. I think MT2 is +ve with respect to MT1 in quadrants I and II; and MT2 is –ve with respect to MT1 in quadrants III and IV.*



Corrected Fig.1. from Circuit Surgery *Jan 2015 – Diac and Triac symbols*

The problem was not so much with the position of the symbols, but with the labelling of MT1 and MT2 – these are swapped on all the triacs in Fig.4 (and Fig.1). The problem occurred in the production of the figures; unfortunately the original text was edited to match the incorrect figures – the following text and figures are now correct.

The fact that triacs can conduct in both directions and can be triggered by gate currents of either polarity leads to four possible triggering scenarios, or quadrants, as illustrated in Fig.4. Positive half-cycles of the AC waveform correspond to quadrants I and II in the upper half of Fig.4. The triac's MT2 terminal is positive with respect to MT1. Negative half cycles of the AC waveform correspond to quadrants III and IV in the lower half of Fig.4. The triac's MT2 terminal is negative with respect to MT1.



Corrected Fig.4. from Circuit Surgery *Jan 2015 – Triac Quadrants*

Thanks to Chris for bringing this to our attention and for being complimentary about the article, despite the error.

Stopper resistors and capacitive loads

In *EPE Chat Zone*, ***james*** posted a question about one of the op amp circuits in the *PortaPAL-D* project (*EPE*, December 2014, page 14).

All three pre-amps in this project have 150R series resistors at their outputs. The text on page 15 describes these resistors as 'stopper resistors'. My question is: 'What is the purpose of a "stopper resistor" and how does it perform its function?'

In response, ***zeitghost*** *highlighted the use of the term in the context of valve amplifiers (eg, guitar amplifiers), specifically as 'grid stoppers'. This seems to be by far the most common use of the term 'stopper resistor', but this term is not used exclusively in this context. We will take a quick look at that first, before looking at the op amp circuit from the* Portapal-D*, followed by a discussion on addressing instability due to capacitive loading of op amps, which is one of reasons why an output resistor might be used.*

Grid stoppers

Fig.1 shows an outline schematic of a typical valve amplifier stage. For those readers unfamiliar with valves, it may help to know that the circuit is similar to a FET amplifier and, like a FET, the valve has very high input impedance, but with significant capacitance between the grid and other terminals. The grid stopper resistor is placed between the input and the grid, as close to the grid as possible. It forms a low-pass filter in conjunction with the valve's internal capacitance.

Valve audio amplifiers are susceptible to picking up radio signals, which are rectified by the valve (acting like a diode) and so can be heard on top of whatever is being amplified. The reduction of gain at high frequencies by the grid stopper (plus valve capacitance) attenuates the radio signal before it can be rectified and therefore reduces or eliminates the problem.

Like all amplifiers, valve circuits can become unstable and oscillate (more on this in the context of the op amps later) and grid stoppers help to reduce gain at high frequencies and improve stability.

Grid stopper resistors also limit grid current. Normally, the grid is high

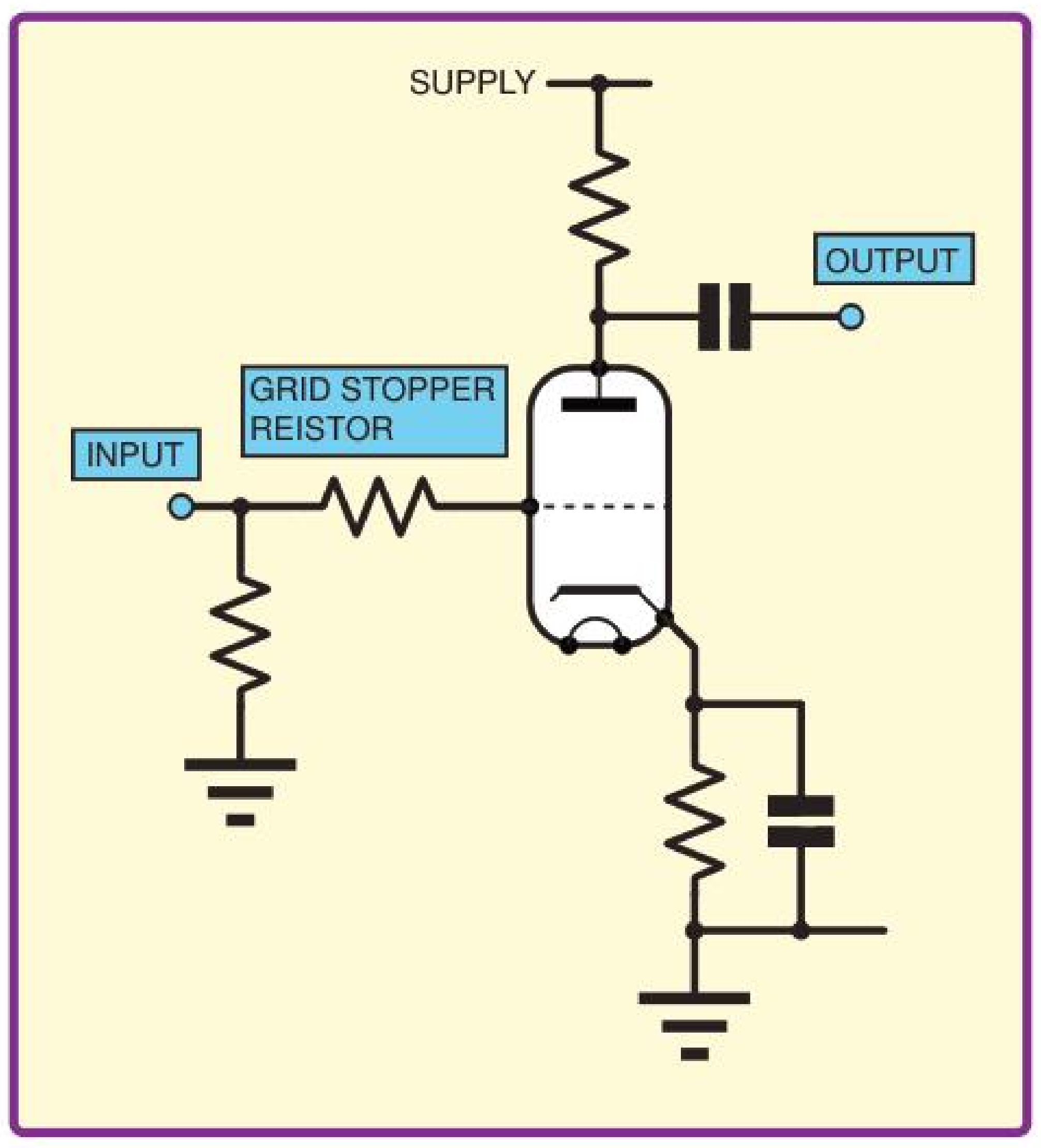


Fig.1. Valve amplifier showing grid stopper resistor

impedance, as previously mentioned, but at high grid drive levels (relatively more likely in guitar amplifiers) it starts to conduct. This can overload the preceding stage, which causes significant distortion (known as blocking distortion). Furthermore, sufficiently high grid current will damage the valve and a grid stopper will help prevent this.

Stopper resistors similar to grid stoppers are used in some transistor circuits, particularly for FETs, where they are referred to as 'gate stoppers' although they are required less frequently than with valve circuits. Grid stoppers, although they are an interesting topic for valve enthusiasts, are not really relevant to ***james's*** enquiry. The resistor in question is on the output of an amplifier circuit, not the input, so we are not in the same situation as a grid stopper.

Back to op amps

The *PortaPAL-D* has two microphone preamps, using an LM833 op amp and a guitar preamp using a TL071. We will look at one of the microphone preamps in detail – the same principles will apply to the use of the output resistor in the other situations.

The LM833 is a dual operational amplifier available from a number of manufactures (Texas Instruments, ST Microelectronics and ON Semiconductor). It is a general-purpose op amp, designed with emphasis on audio applications. The possible requirement for a resistor on the output is covered in the Texas Instruments datasheet, which says:

The LM833-N is a high-speed op amp with excellent phase margin and stability. Capacitive loads up to 50pF will cause little change in the phase characteristics of the amplifiers and are therefore allowable.

Capacitive loads greater than 50pF must be isolated from the output. The most straightforward way to do this is to put a resistor in series with the output. This resistor will also prevent excess power dissipation if the output is accidentally shorted.

A simplified version of one microphone preamp circuit from the *PortaPAL-D* is shown in Fig.2 (microphone phantom power and single supply reference are not included). The components forming the input of the next stage (level control into the mixer) are shown as a load. This circuit is a version of the classic op amp differential amplifier shown in Fig.3. As its name suggests, this circuit amplifies the voltage difference between the two inputs, which in the case of the *PortaPAL-D* microphone preamp is the balanced output from the microphone. The gain of the circuit is given by:

$$\text{Gain} = \frac{R_2}{R_1} = \frac{R_4}{R_3}$$

Here, the gain is 22.

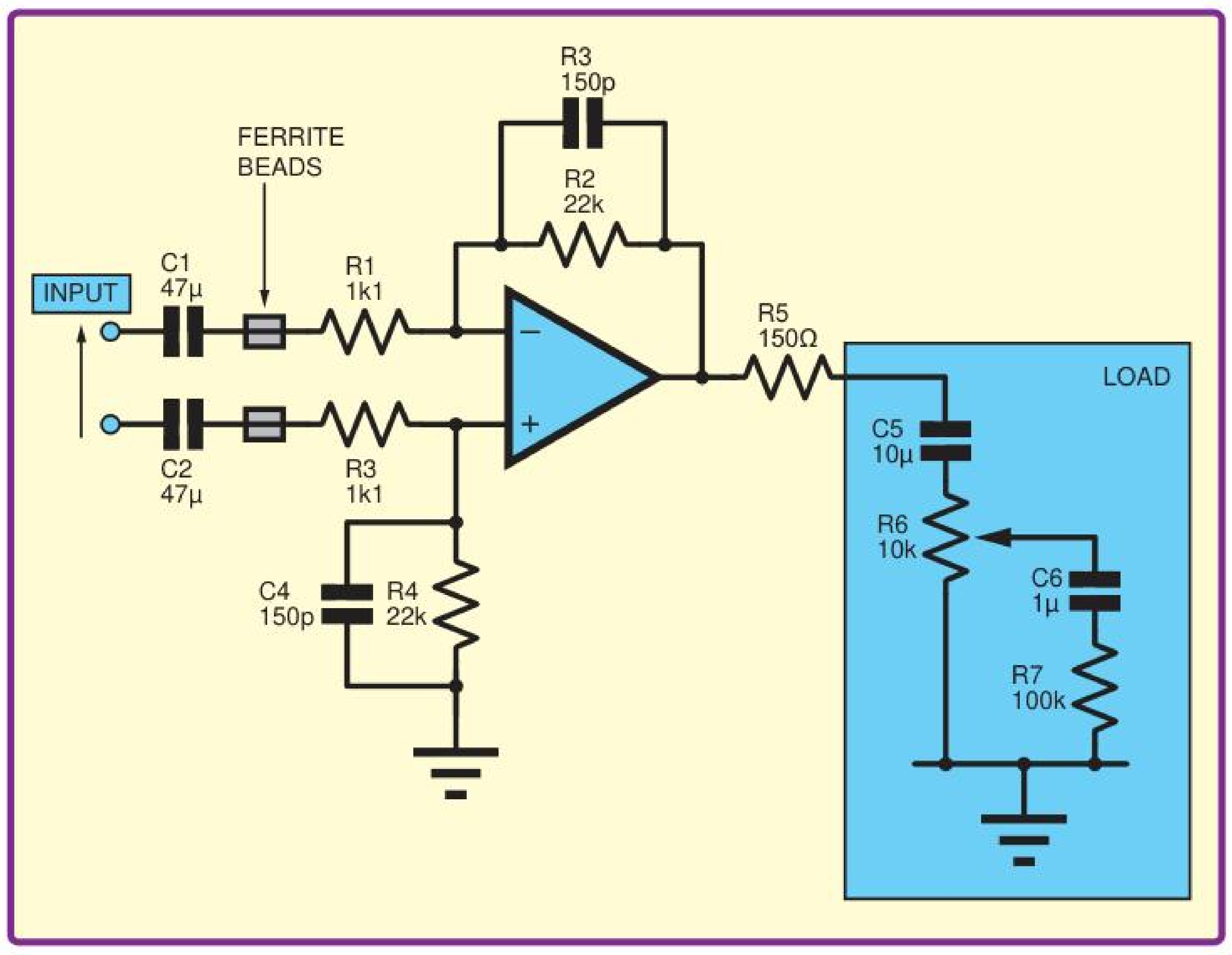


Fig.2. Simplified schematic of the PortaPAL-D microphone preamplifier with the level control/mixer input shown as a load

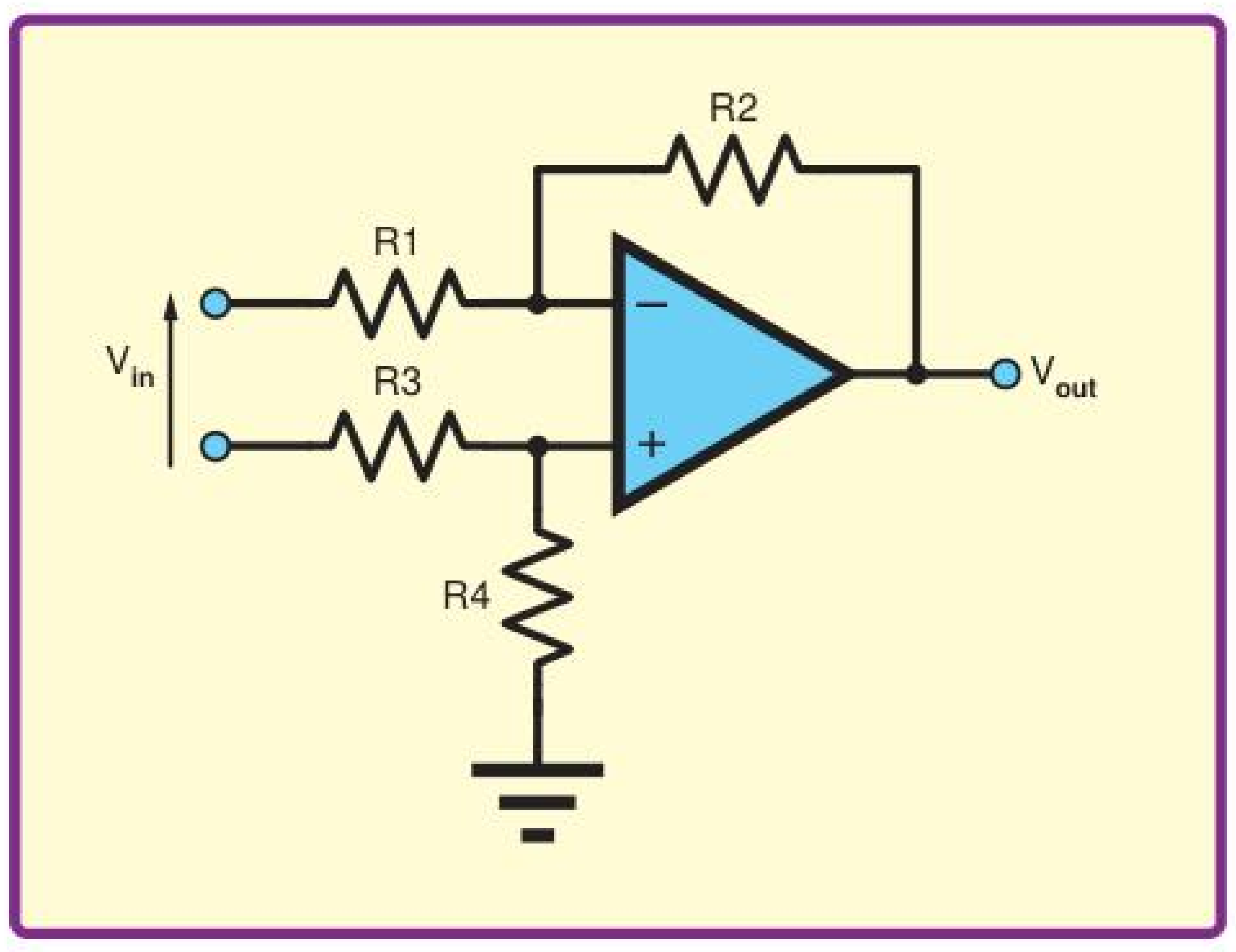


Fig.3. Basic op amp differential amplifier configuration

Differential amplifiers

Having introduced the microphone preamplifier circuit, it is worth looking at it in a little more detail, explaining why it is used and highlighting a limitation of the circuit in Fig.3, in case readers want to use it for other purposes.

If a signal is carried on two wires, as the difference in voltage between those wires, then it is called a differential signal. In audio systems this is referred to as a balanced signal. Note that the amplitude of a differential signal is not measured with respect to ground. A signal carried as a voltage on a single wire, with reference to ground, is called a single-ended signal or unbalanced signal in audio terminology. Many microphones provide a balanced output because it reduces susceptibility to noise.

The two wires carrying a differential signal between them may also have a voltage, which is same on both wires. This is known as a common-mode signal, and is basically the average of the voltage on the two wires at any time. If we amplify the voltage difference between two wires carrying a differential signal, the common-mode voltage will have not have an effect on the amplifier's output (taking the difference between equal values gives zero). In the case of a microphone this is useful because the wiring may pick up unwanted signals, such as mains hum. Microphone signals are small, so it would not take much induced hum for it to be noticeable. However, because the two writes carrying the differential signal are the same length, and more or less in the same place, they will both pick up the same hum signal – so the hum will be a common-mode signal and will not be amplified by a differential amplifier.

That is the ideal case, but real differential amplifiers are not perfect at rejecting common-mode signals. Their ability to do this is described by their common-mode rejection ratio (CMRR). This is the ratio between the gain for differential and common-mode signals, usually expressed in decibels (dB). Op amps are differential amplifiers and often (but not always) have very good CMRR. For example, the datasheet gives a typical value of 100dB for the LM833, meaning the differential gain is 100,000 times larger than the common-mode gain.

The differential amplifier in Fig.3 does not have a CMRR equal to that of the op amp's. In fact, its CMRR depends strongly on how close the ratio of the resistors R_2/R_1 is to the ratio of resistors R_4/R_3 (the gain equation above implies these ratios must be equal). If these are very well matched, the CMRR can be high, but the resistors have to have a very good tolerance for this, which is why 1% resistors are specified in the *PortaPAL-D* project.

The CMRR ratio in decibels of the circuit in Fig.3 is given by:

$$\text{CMRR} = 20\log\left(\frac{k+1}{4t}\right)$$

Where k is the gain of the circuit and t is the tolerance. This equation was published in a paper by Ramón Pallás-Areny and John Webster in 1991. This equations show that the circuit in Fig.3 can provide very poor performance as a differential amplifier, for example a unity-gain circuit using 5% (0.05) resistors will have a CMRR of only 20dB:

CMRR = 20 × log (2/4 × 0.05))

20 × log(10) = 20dB (even with an ideal op amp)

For the circuit in Fig.2, the above equation indicates a CMRR of about 55dB, which given that any hum is likely to be at a low level if shielded microphone cables are used, is fine. However, in other applications requiring very high CMRR, the circuit in Fig.3 may be less useful unless the resistors are very well matched (integrated differential amplifiers with laser-trimmed resistors are available). An alternative is to use an instrumentation amplifier.

Frequency response

The circuit in Fig.2 has a number of components added with respect to Fig.3, which modify its frequency response. The circuit in Fig.3 amplifies from DC to frequencies limited by the op amp's bandwidth, whereas the circuit is Fig.2 covers a range suitable for audio signals. The coupling capacitors C1 and C2 block DC at the input. Capacitors C3 and C4 in parallel with R2 and R4 reduce the gain of the circuit at high frequencies.

The impedance (Z_C) of a capacitor, C, at frequency f is given by: $Z_C = 1/2\pi fC$. When the impedance of C3 and C4 equal the value of the resistors R2 and R4 respectively the circuit's gain will be halved. This occurs at $f = 1/2\pi RC = 1/(2\times\pi\times22\times10^3\times150\times10^{-12}) = 48$kHz.

The circuit in Fig.2 has ferrite beads on its inputs. These increase the inductance of the inputs, which blocks very high frequencies, helping to prevent problems with RF pickup – the same function as one of the uses of the grid stopper resistor we discussed earlier.

The load on the microphone preamp comprises the coupling capacitors and level potentiometer, and is drawn in Fig.2 as a group of components connected to ground rather than the layout in the conventional manner of the original schematic. This is simply to emphasise the fact that there is significant capacitance in the load, although it is connected via resistance.

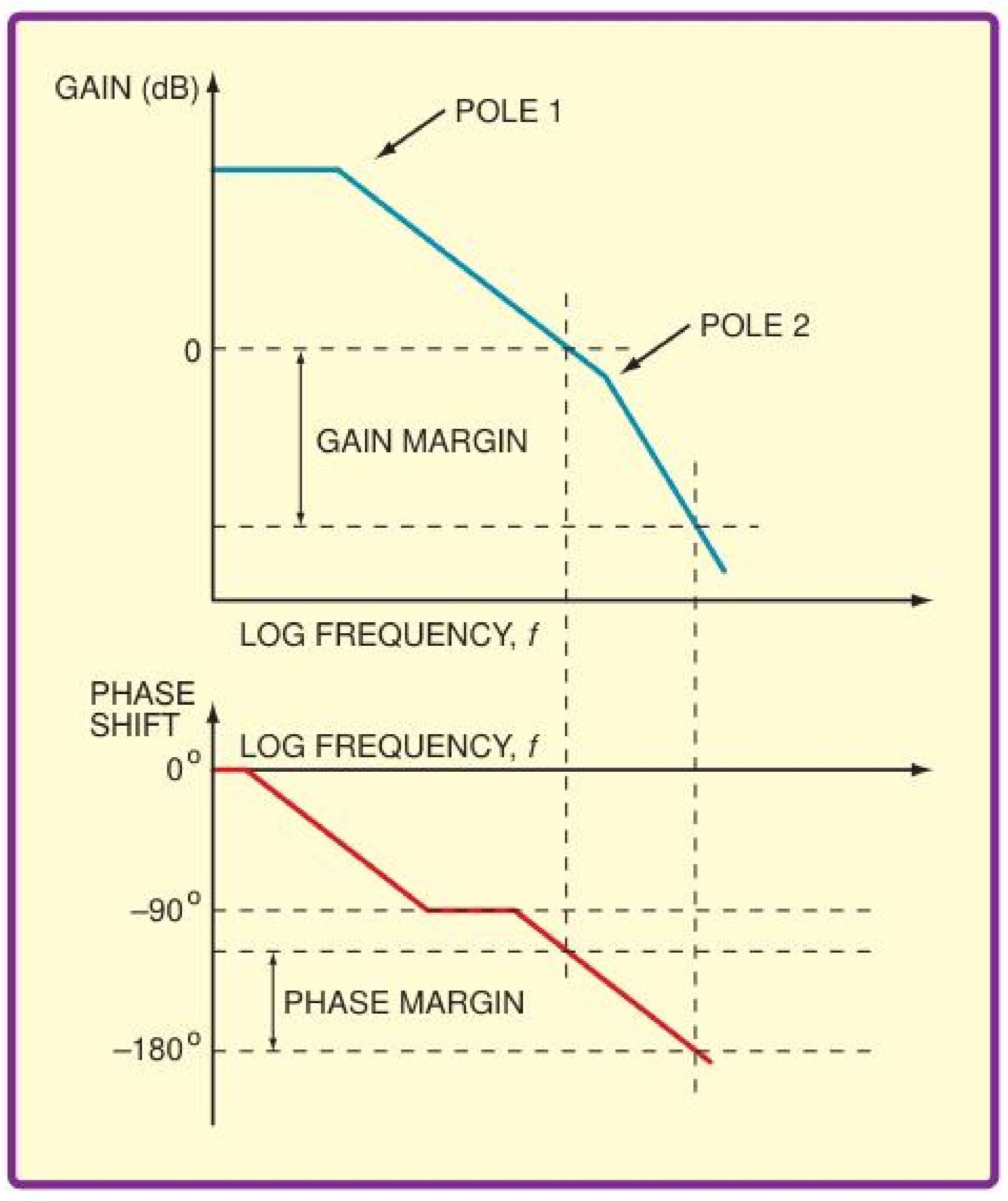


Fig.4. Variation of gain and phase shift around a feedback loop with signal frequency, illustrating gain margin and phase margin

The frequency response of the circuit is directly related to the need for the inclusion of the output resistor R5. To understand why this is needed we need to discuss the issue of feedback stability. We discussed this recently (*Circuit Surgery*, *EPE* November 2014) in the context of linear regulator circuits – we will summarise the concepts again briefly now.

Circuit stability

The output of a circuit does not respond infinitely quickly to changes at its input, so a feedback signal will be delayed with respect to the input. For example, assume for simplicity a fixed delay from input to output of the feedback network of 0.1µs. If the input frequency was 100Hz this time would only be 0.001% of the signal's cycle time (a phase shift of 0.0036°) and would probably be insignificant. If delay is fixed, then phase shift increases proportional to frequency. So, at 5MHz, 0.1µs is half the cycle time of signal (180°). This is a significant point because a phase shift of 180° is equivalent to multiplying the signal by –1. What was *negative* feedback has now become *positive* feedback.

Positive feedback is what you need to make an oscillator, so our circuit may become unstable. For this instability to occur, the gain around the feedback loop must be one or more at the frequency at which the phase shift reaches 180°. The question is – will the above conditions for instability occur as frequency increases?

We can represent how close a circuit is to being unstable using the concepts of gain margin and phase margin. As gain around the feedback loop approaches 1, the phase shift must be less than 180°. The difference between the phase shift at this point and 180° is the *phase margin*. Second, as the phase shift around the loop approaches ±180° the magnitude of the gain must be less than 1. This difference can be expressed as the *gain margin* (usually in dB). Any change in a circuit's structure or component values may change its stability for better or worse.

If a circuit has poor gain and phase margin then it may not oscillate all the time, but changes in parameters such as temperature or component aging may make things worse, leading to sustained oscillation. Furthermore a circuit with poor gain and phase margin is likely to ring (produce decaying oscillations) if large input signal changes occur. If the frequency response is completely unstable (zero or negative gain and phase margin) then it will oscillate permanently.

Fig.4 shows a typical frequency response plot for an amplifier such as an op amp. There are a couple of breakpoints where the gain starts to decrease more rapidly as frequency increases. These breakpoints are called *poles* and, in simple terms, can each be thought of as relating to a single RC low-pass filter somewhere in the signal path (such as that formed by R2 and C3, which was discussed above).

At frequencies above the pole frequency, gain decreases at a rate of 20dB per decade of frequency *more* than below the pole, and the phase shift is increased by 90°. There is another type of breakpoint which can occur in frequency responses. This is called a *zero*. Gain will decrease at a rate of 20dB per decade of frequency *less* above a pole compared to below it.

Adding poles and zeros to a circuit's feedback loop changes the stability of the circuit. For example, adding a pole may make a circuit more unstable because it causes the phase shift to increase. However, it also may make the circuit more stable because the gain is reduced at high frequencies. The actual situation will depend on the relationship of *all* the poles and zeros in the frequency response.

Capacitive loads

When we add a capacitive load to an op amp amplifier, as shown in Fig.5, we form an RC low-pass filter with the op amp's output resistance. This will add a pole to the circuit's frequency response, which increases delay around the feedback loop, increasing the phase shift and hence reducing phase margin. The circuit often becomes more unstable, although it is possible for op amps to be stable for low capacitive loads, unstable for a wide range of larger loads, but stable again for higher capacitor values. This is because adding the load capacitor reduces gain at high frequencies as well as increasing phase shift. With a very large capacitive load the circuit may be stable, but will be slow.

There is another way to think about op amp instability with capacitive loads. The effective output resistance of an op amp is reduced by feedback – however, as frequency increases the gain of the op amp decreases and therefore so does the amount of feedback. This increases the effective output impedance from a low value towards the open-loop output impedance. Increasing impedance with

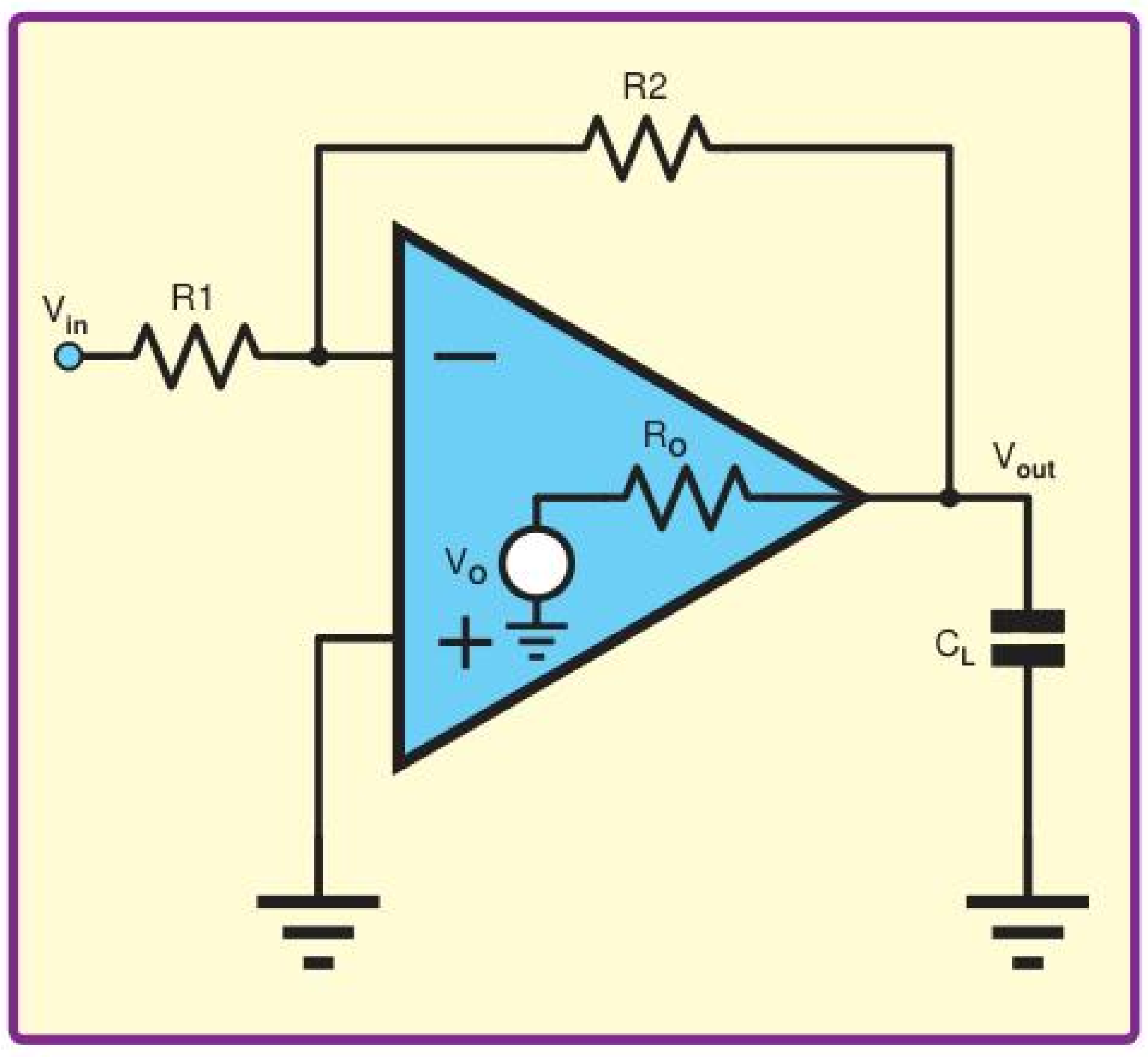


Fig.5. Op amp amplifier with capacitive load showing op amp output resistance

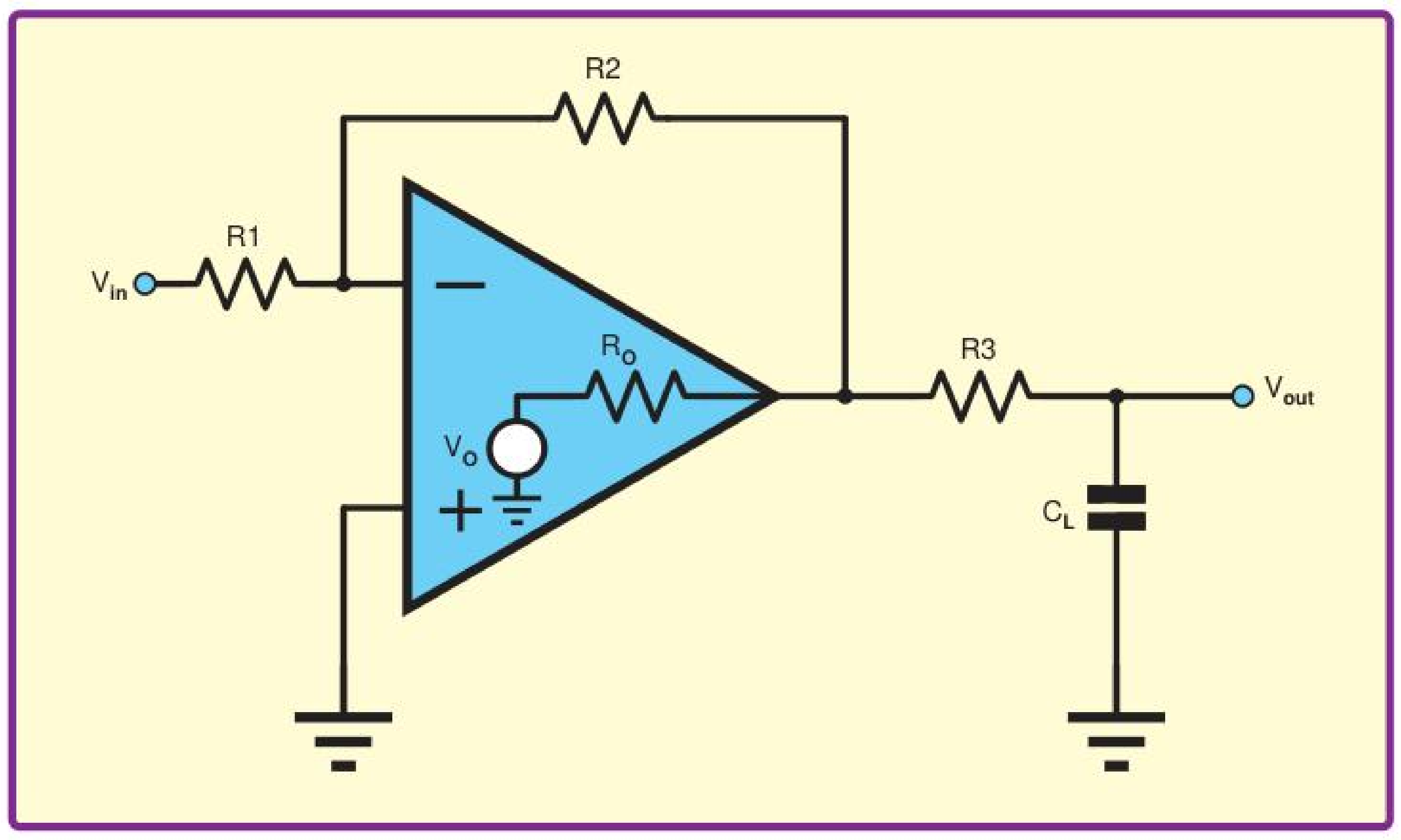


Fig.6. Op amp amplifier with capacitive load and isolation resistor

increasing frequency is like the behaviour of an inductor, so R_O really looks like it has an inductance in parallel with it. This inductance forms a resonant circuit with the load capacitance, which may result in ringing or oscillation. In the frequency response we may see a resonant peak.

There are a number of ways to improve the stability of a circuit in which an op amp drives a capacitive load. The simplest is to add a resistor between the op amp's output and the capacitor, as shown in Fig.6. This isolates the capacitor from the op amp's feedback circuit and modifies the frequency response to a more stable situation. We can also think of it damping the resonant circuit that we just discussed. Other approaches include the output resistor and capacitor in the feedback loop.

Fig.7 shows LTSpice simulation results for three op amp circuits like the one in Fig.5 (R1 = 1kΩ, R2 = 3kΩ, LT1817 op amp) with a step input of 0.5V in 100ns. The first circuit (upper trace) has no load capacitance (no C_L), the second (middle trace) has a load capacitance of C_L = 5nF and the third (lower trace) also has a load capacitance compensation resistor of 150Ω (R3 in Fig.6). It can be seen that the circuit with just the load capacitance has stability problems – ringing occurs after the step input. With a slightly larger capacitor, the circuit oscillates permanently. The resistor allows the capacitor to be driven without ringing.

Fig.8 shows the input to output frequency response of the same three circuits as in Fig.7. Note the resonant peak in the middle trace's response. This is typical for circuits that exhibit ringing

Having presented some simulation results it is worth noting that it is difficult to obtain exact simulations of the specific stability of particular op amps and circuits built with them. This is because the simulation models provided for the op amps may not include all the details of frequency response and because it is easy to miss, or simply not have the right values for parameters such as temperature, wiring capacitance and inductance, capacitor series resistance or supply impedance, all of which might influence the stability of a real circuit. Experimenting with simulations can, however, be very helpful for exploring the basic principles of circuit stability and getting a general feel for the stability of a real design.

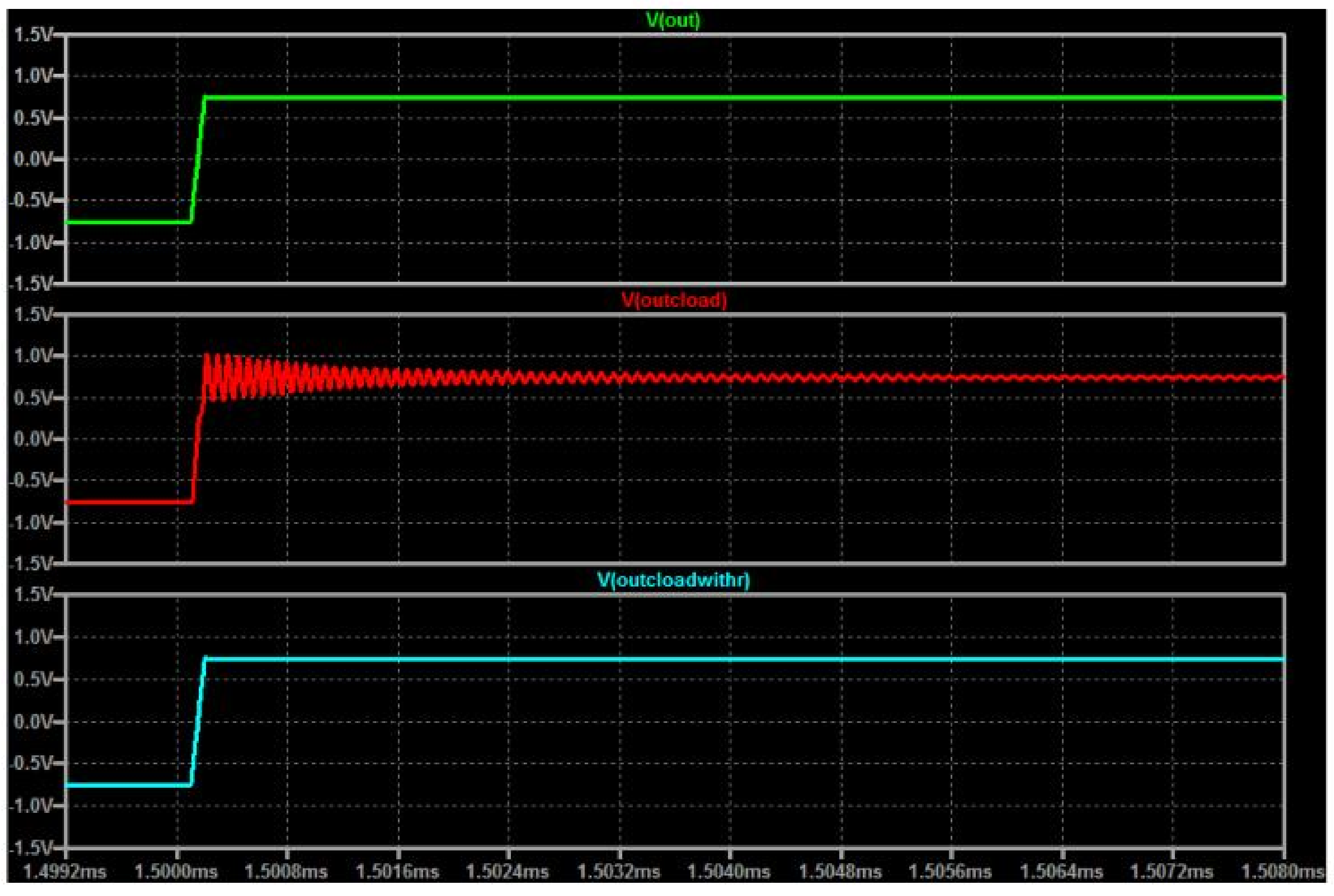


Fig.7. Simulated response of three op amp circuits to a step input. Upper trace: no capacitive load, middle trace: capacitor connected to op amp output, lower trace: capacitor connected via a resistor

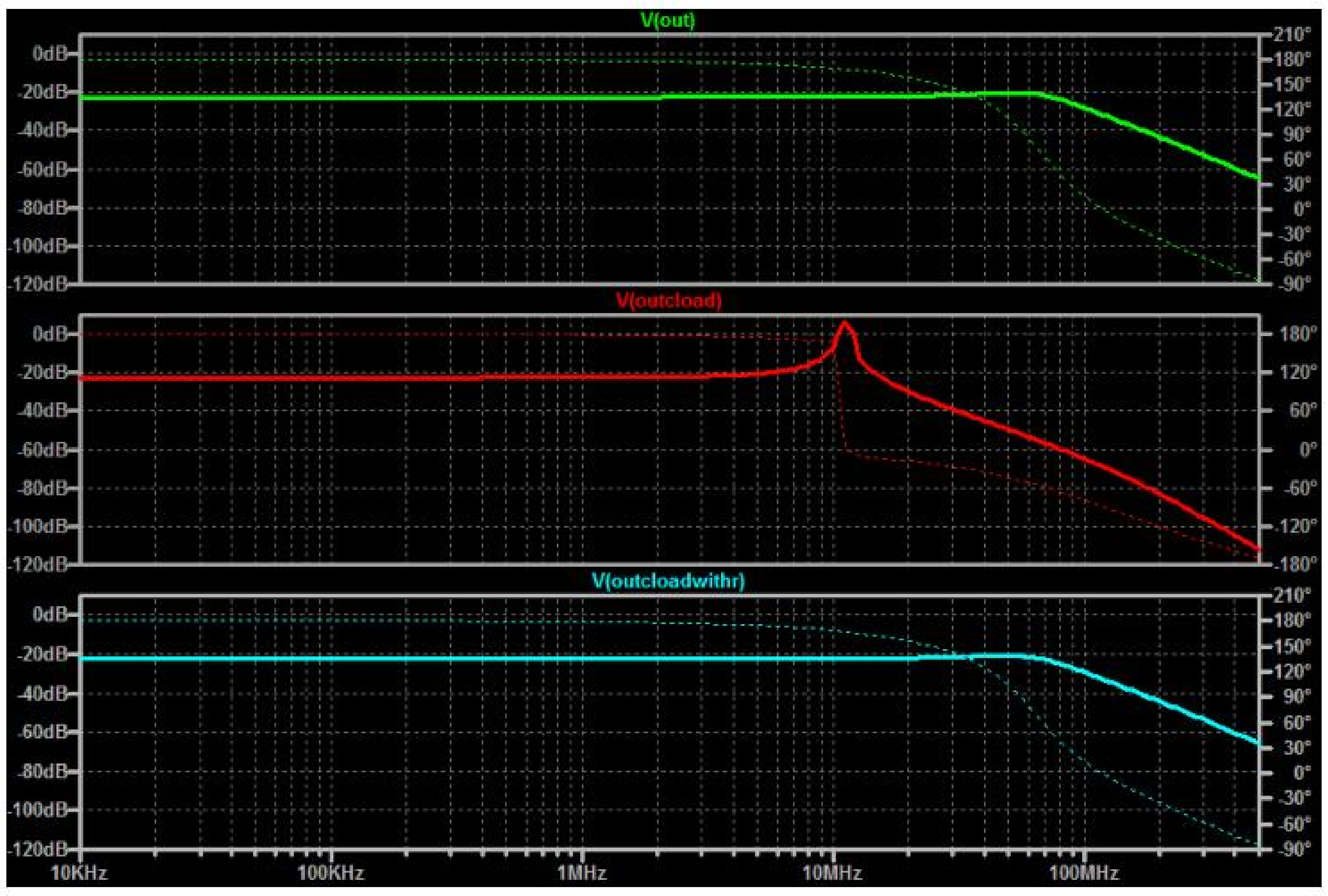


Fig.8. Simulated frequency response of three op amp circuits. Upper trace: no capacitive load, middle trace: capacitor connected to op amp output (Fig.5), lower trace: capacitor connected via a resistor (Fig.6)

Op amps could be designed internally to be able to cope with large capacitive loads without instability; however, this tends to reduce their performance with light capacitive loads, so many op amps have a maximum capacitive load value, which is quite small (consult a device's datasheet for details). However, some op amps are designed specifically for capacitive loads, for example the C-Load family of op amps from Linear Technology.

Reference

Ramón Pallás-Areny and John G.Webster. *Common Mode Rejection Ratio in Differential Amplifiers*, *IEEE Transactions on Instrumentation and Measurement*, Vol. 40, No. 4, August 1991, pp. 669-76.

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PIC n' Mix

Mike Hibbett

Our periodic column for PIC programming enlightenment

Adding PWM to the development board

THIS month will be the last in the current series of adding code to our development board template code library; so it's fitting that we conclude with one of my favourite add-ons, the *pulse-width modulation* (PWM) peripheral. Why is it my favourite? Because it can bring projects to life, as you will see.

In its simplest form, the PWM peripheral generates a periodic pulse on a digital output pin. You can see some examples of the effect in Fig.1. PWM signals are defined by two parameters: the *period*, that is the duration of a single cycle, expressed in hertz, and the *duty*, which specifies the percentage of time that the signal is high. Fig.1 shows increasing duty percentage, from top to bottom, with a fixed period.

In normal applications the period is fixed; the frequency used is dependant on the physical demands of the electronics, and load.

So what is it actually used for? As it turns out, it has several uses.

A PWM signal can be used as a poor-man's digital-to-analogue converter. When fed through a low-pass filter, such as an RC network, it can be used to generate a continuous voltage between 0V and 3.3V.

Radio-control servomotors use a PWM signal to control the rotation of a motor. A variable resistor coupled to the drive shaft of the motor generates a voltage proportional to the angular position of the motor, and a comparator is used to compare the voltage of the variable resistor against the analogue voltage generated by the PWM signal. The 'difference' between the two voltages causes the motor to rotate until they are the same. It's a simple negative feedback closed-loop system, designed so that no microprocessor is required. You can see an example of this in Fig.2.

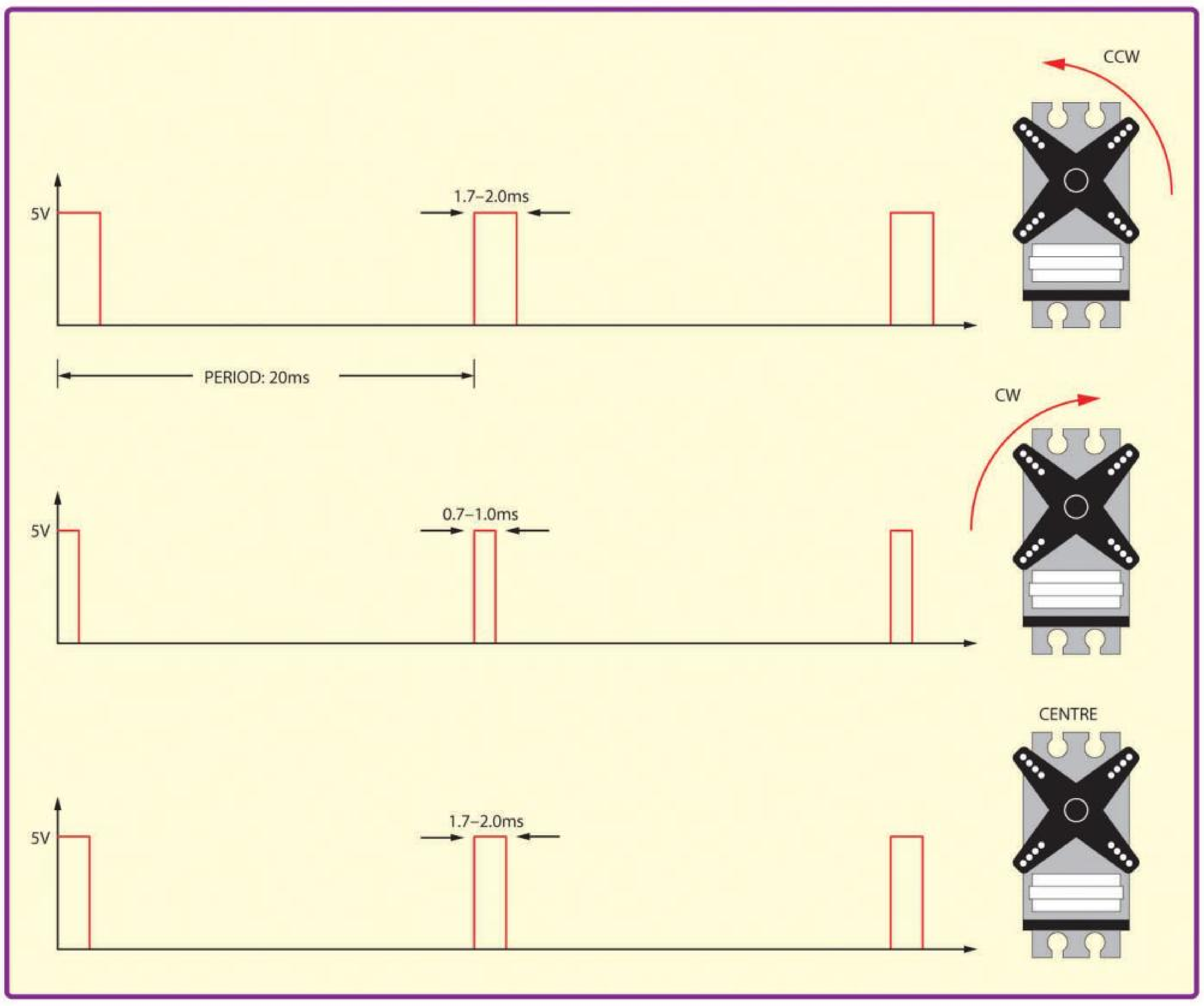

Fig.2 PWM module

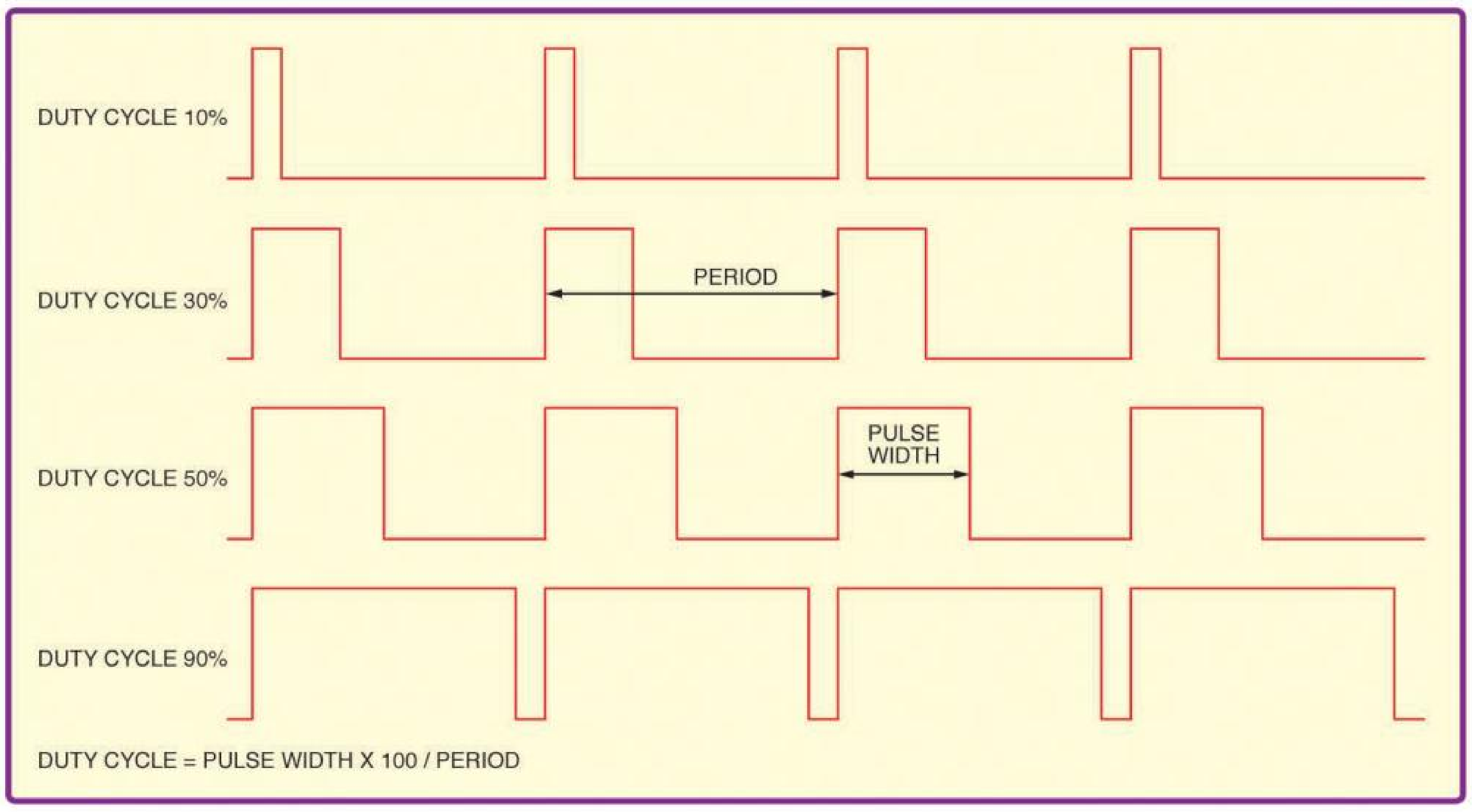

Fig.1 PWM signal

PWM signals are also used to turn electrical loads on and off quickly to vary the power being delivered, for example with heaters, PC fans and switch-mode power supplies. It's even possible to generate audio with a PWM signal, although you won't win any awards for sound quality using a PIC PWM peripheral.

PWM signals generally run at a period of between a few hundred hertz (for RC servo control) to a few tens of kilohertz for PC fan controllers. If you are using the signal to generate an analogue voltage for your own purposes, remember that the time constant of the RC filter will limit how quickly you can change the voltage, and also that the signal you create with an RC filter will need to be carefully isolated from the next stage of the circuit if its impedance is too low, or it adds significant capacitance. In other words, you need to buffer the output.

Running PWM from PICs

Microchip's PWM peripheral allows for up to ten bits of resolution on the duty cycle setting. If you need to run the PWM at a high frequency (for generating audio or controlling a

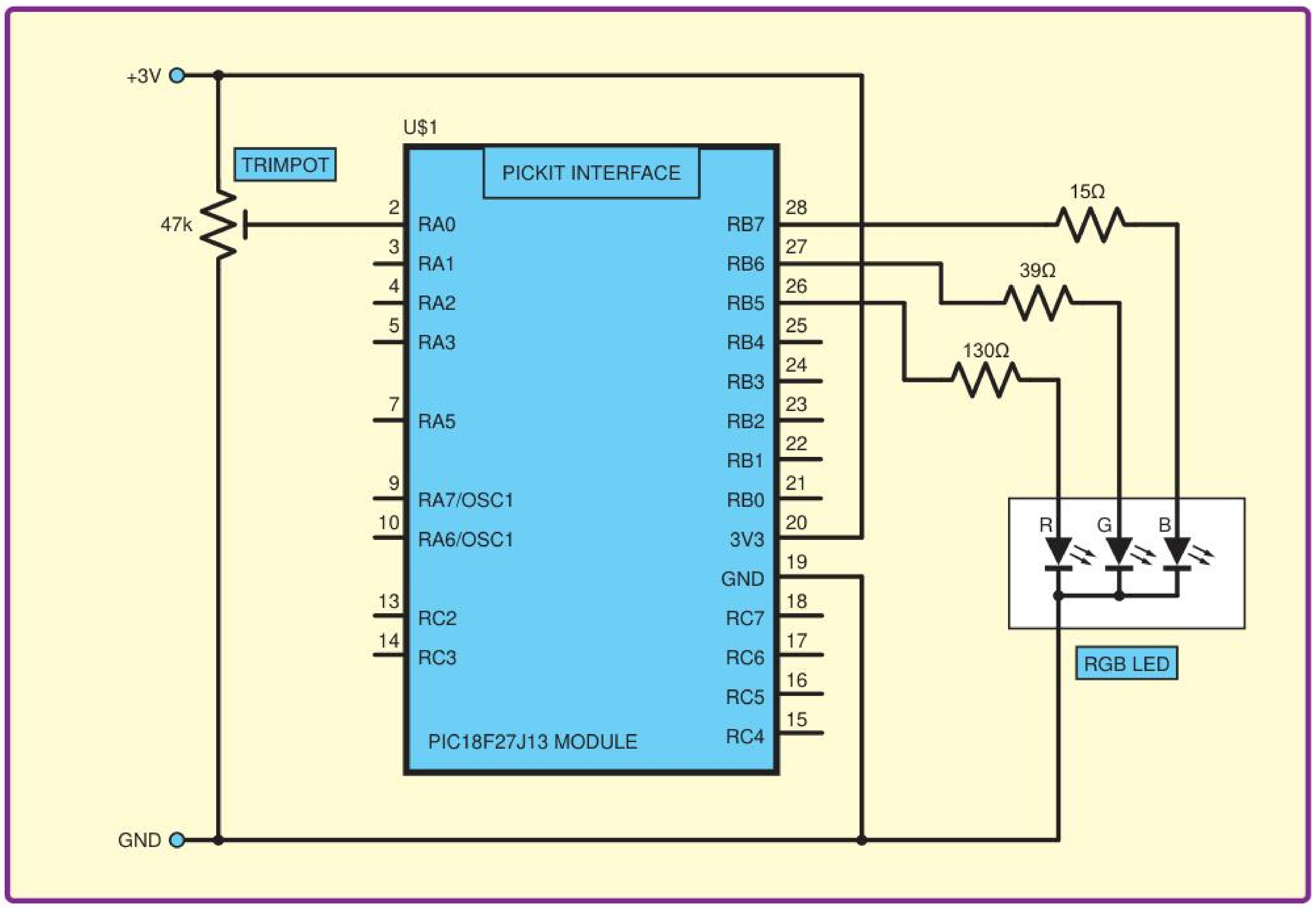

Fig.3 Using PWM – driving an RGB LED

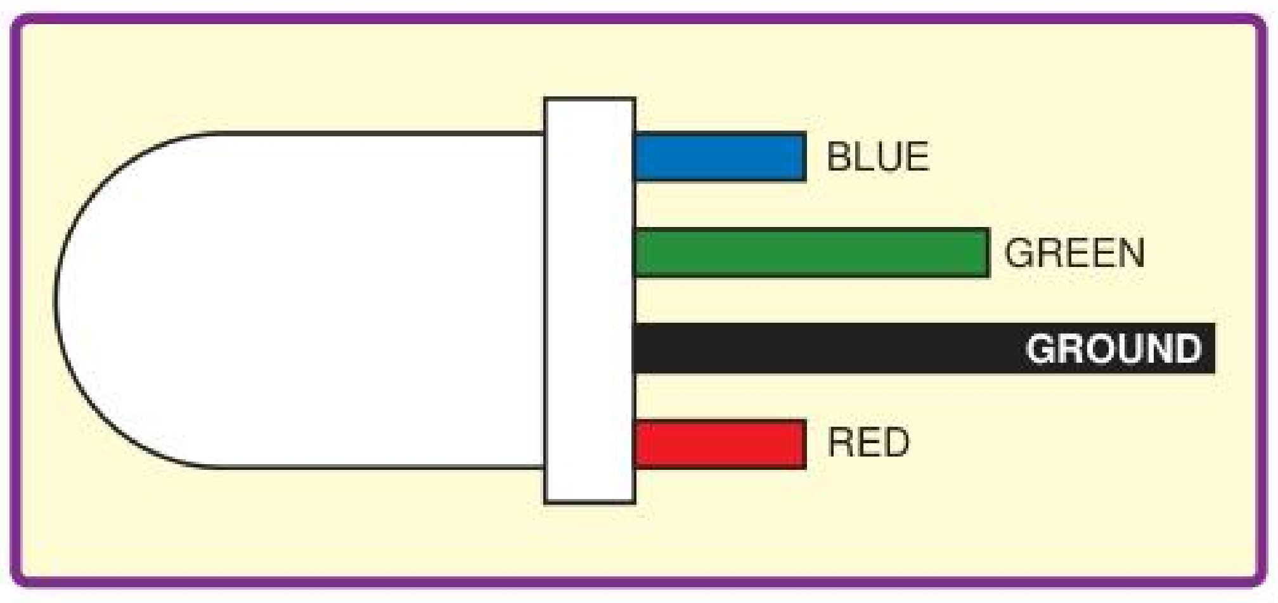

Fig.4 Typical RGB LED pin-out

switched-mode power supply for example) then the number of bits available for the duty setting falls to as low as four bits at 400kHz. For typical uses of a PWM signal (RC servomotor or PC fan speed control) the frequency required is under 30kHz, and in these cases the resolution is the full ten bits. This gives about one thousand steps, or about 3mV per step if you are generating an analogue voltage.

Unlike analogue-to-digital conversion, where you really have to use an ADC peripheral to achieve the functionality required, it is possible (and indeed easy) to 'bit-bash' a PWM controller. The processor's PWM peripheral will always be more efficient – it manages the 'turn on/turn off' of the output pin with no software intervention – but it is possible to control a dozen or more PWM outputs through a bit-bashing approach with minimal software overhead. This may be an ideal solution to projects with many RC servos, such as animatronics, because RC servomotors have a relatively slow period (about 2ms, but frequently quoted as a frequency, 500Hz) and so controlling dozens of them would not be difficult.

The standard PWM peripheral within the microcontroller can independently control six output pins on our board, so adding bit-bashed PWM control is not really necessary. Bit-bashed PWM control would be more appropriate on a processor package with more pins, where the number of I/O pins exceeds the number of PWM-controlled pins. The animated dragon's head shown in Fig.5, created by my friend Michal Miszta, is typical of these more demanding applications. It uses six servomotors for control of the head, but for simple life-like motion it was possible to meet the timing and update speed requirements with just our PIC development board. You can see more of Michal's work at: **themodelmaker.net**

Using the PWM library

PWM control adds just three functions to the template code. PWM peripherals are very easy to use; you simply write a value to a register to set the duty cycle as a percentage of 'fully on' – 100 being fully on, and 0 being fully off. To initialise the output you call the `PWMPeriod()` function to choose a timer and set the PWM period in hertz, then `PWMInit()` to specify a pin to be activated. The `PWMDuty()` function allows you to specify the duty percentage for a particular pin. These functions execute very quickly, so it is reasonable to call them in an interrupt routine if you wish, or very frequently in your main loop.

On the device we are using (the PIC18F27J13 if you have forgotten) the peripheral can support up to six PWM outputs. Our library code will make all of them available for use, if desired. A single timer is required when one or more PWM channels are enabled, and by using a single timer we force all PWM channels to share the same period. This should not be an issue as the typical scenario of driving many RC servomotors works with a single PWM period (typically around 2ms).

The PWM controller comes in two flavours, standard and enhanced. We are using the standard mode. The PWM module can do much more than generate a simple PWM waveform; it can be combined with other PWM channels to control motors through half and full-bridge interfaces, with a programmable dead zone. This is standard fair for motor control but it's not a common hobbyist requirement, so we will leave that for another article.

Driving an RGB LED

By way of an example, this month's template code (available for download from the 'Projects' page on the magazine's website at **www.epemag.com**) uses PWM to control an RGB LED.

RGB LEDs were made for PWM control; they are simple to connect, and it is necessary to drive each one with a different PWM duty cycle. RGB LEDs contain three LEDs – red, green and blue – in a clear plastic shell. By varying the duty cycle of the voltage driving each LED you can change the intensity of each LED, and so generate any colour through the additive mixture process. The mixing of the light inside the package is not uniform and so you will want to 'tweak' the drive level to each LED, which is simple with PWM. The effect is not perfect by any means but it's fun and the children love them as night lights!

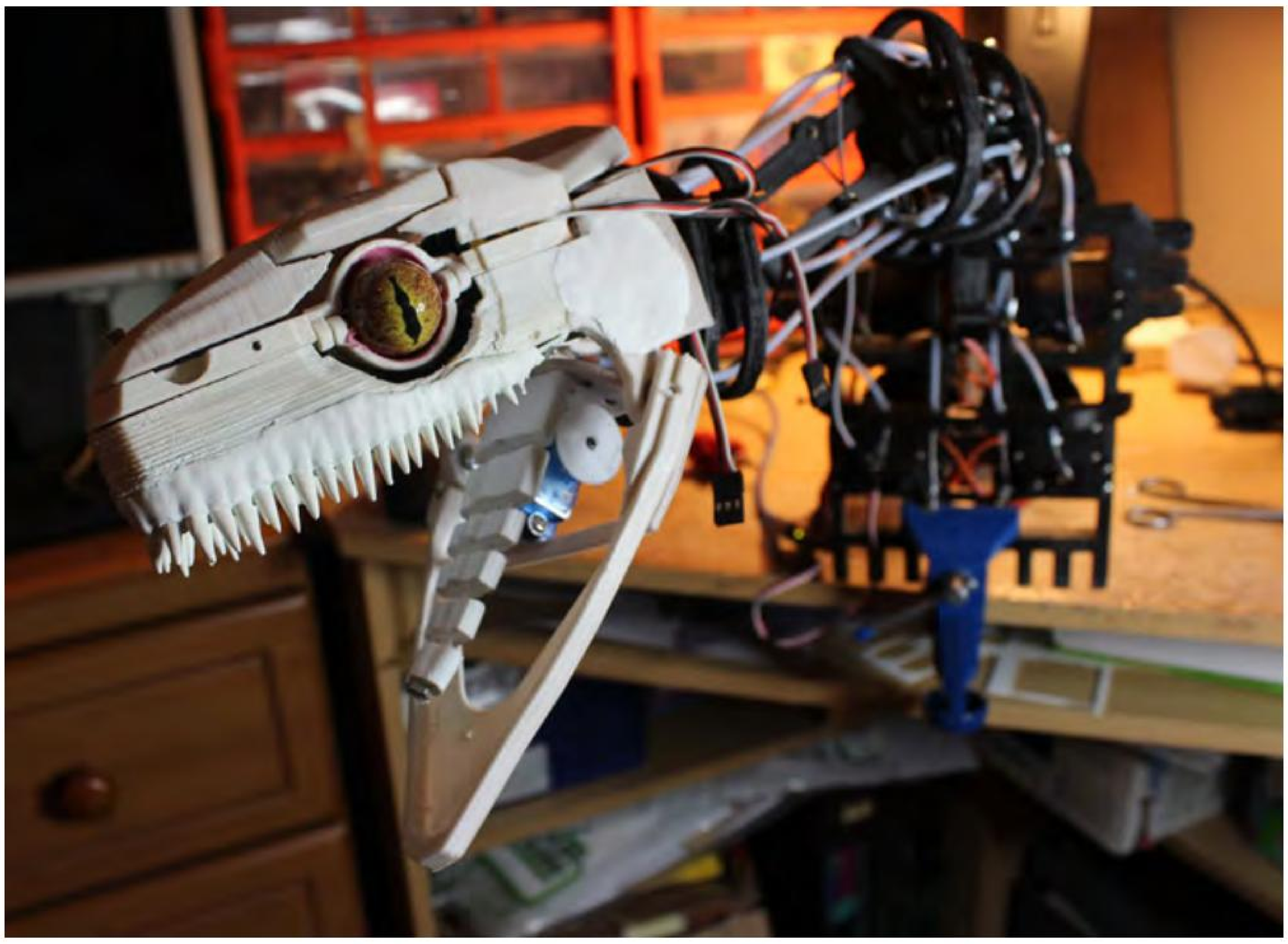

Fig.5 Animated dragon's head, controlled by six servo motors

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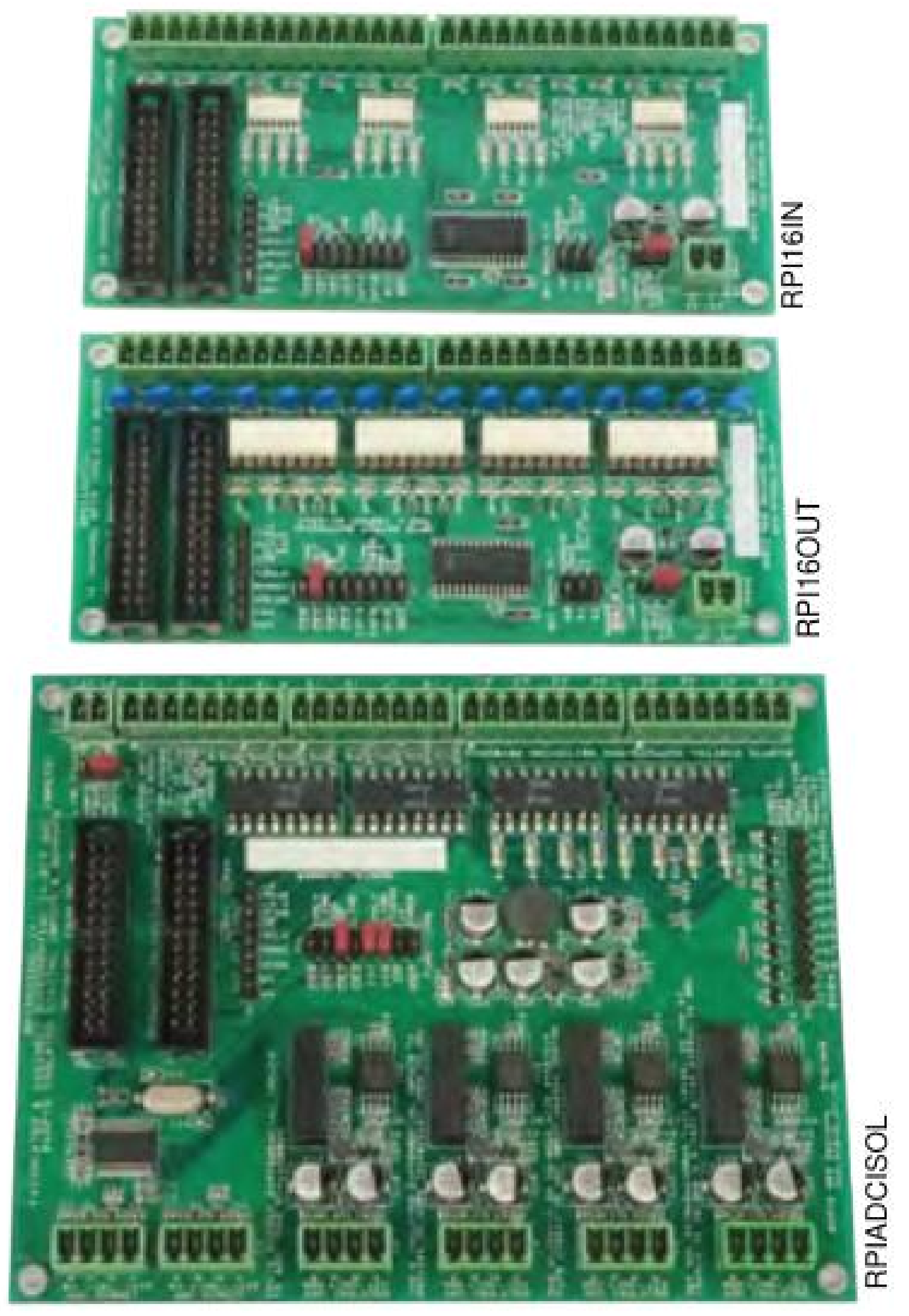

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We've assembled a very simple circuit, shown in Fig.3, to test the process out. The variable resistor in this case is used to set the intensity of the overall light output. The example code cycles round a variety of colours.

It's interesting to note the differences in resistor values for the different coloured LEDs; the values shown are to provide a current of 10mA through each LED. Even with the current being the same, the green led was significantly brighter than the other LEDs and this was compensated for in the code – halving the duty cycle of the green LED. This is another benefit of using a microcontroller PWM signal to control the brightness of an LED; you can dynamically 'calibrate' the intensity of the LED, a procedure normally handled by resistors.

Kickstarter update

As I write this article, the LPLC TOO boards are in my workshop having arrived from the manufacturer in China. The finish and soldering of the tiny components is excellent. I panicked a little at first, as I thought half the components had been left off. Then I realised that I didn't have my glasses on, and I simply could not see them! By the time your read this they should have been delivered to the project backers.

I'm hooked on the Kickstarter process now – it's exhilarating, educational and great fun. I'm already thinking about the next project. If you have any suggestions for something you would like to see created, why not pass by the *EPE* chat forum at **www.chatzones.co.uk/discus** and leave a comment.

Next month

We take a vacation from the development board next month, when we report on a weekend-long hardware 'hackathon' hosted by University College Dublin back in November. It was a weekend without PICs – a chance to play with Arduinos and Raspberry Pis for a change, with a great bunch of enthusiasts and scientists. My team's goal was to create a drum synthesiser in a pair of tracksuit bottoms. The results were hilarious!

Not all of Mike's technology tinkering and discussion makes it to print. You can follow the rest of it on Twitter at **@MikeHibbett**, *and from his blog at* **mjhdesigns.com**

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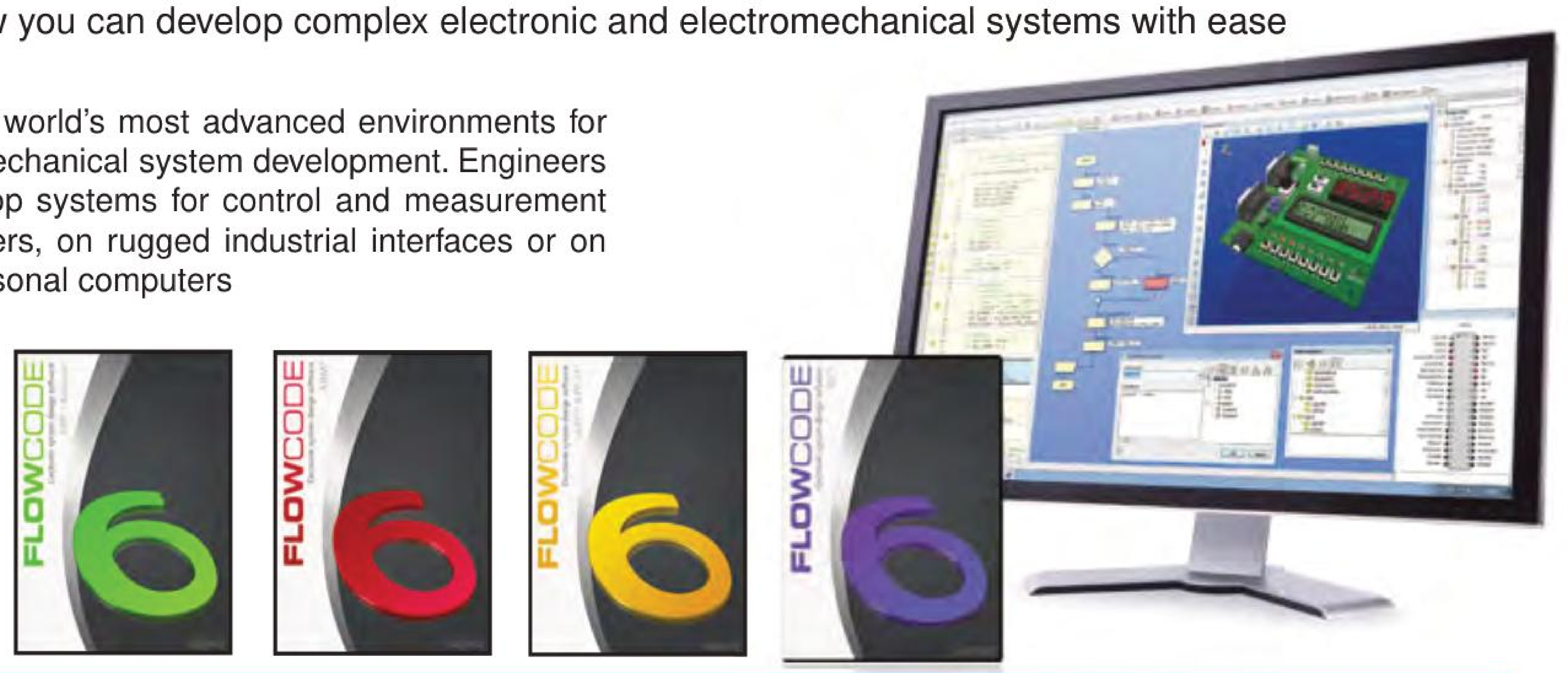

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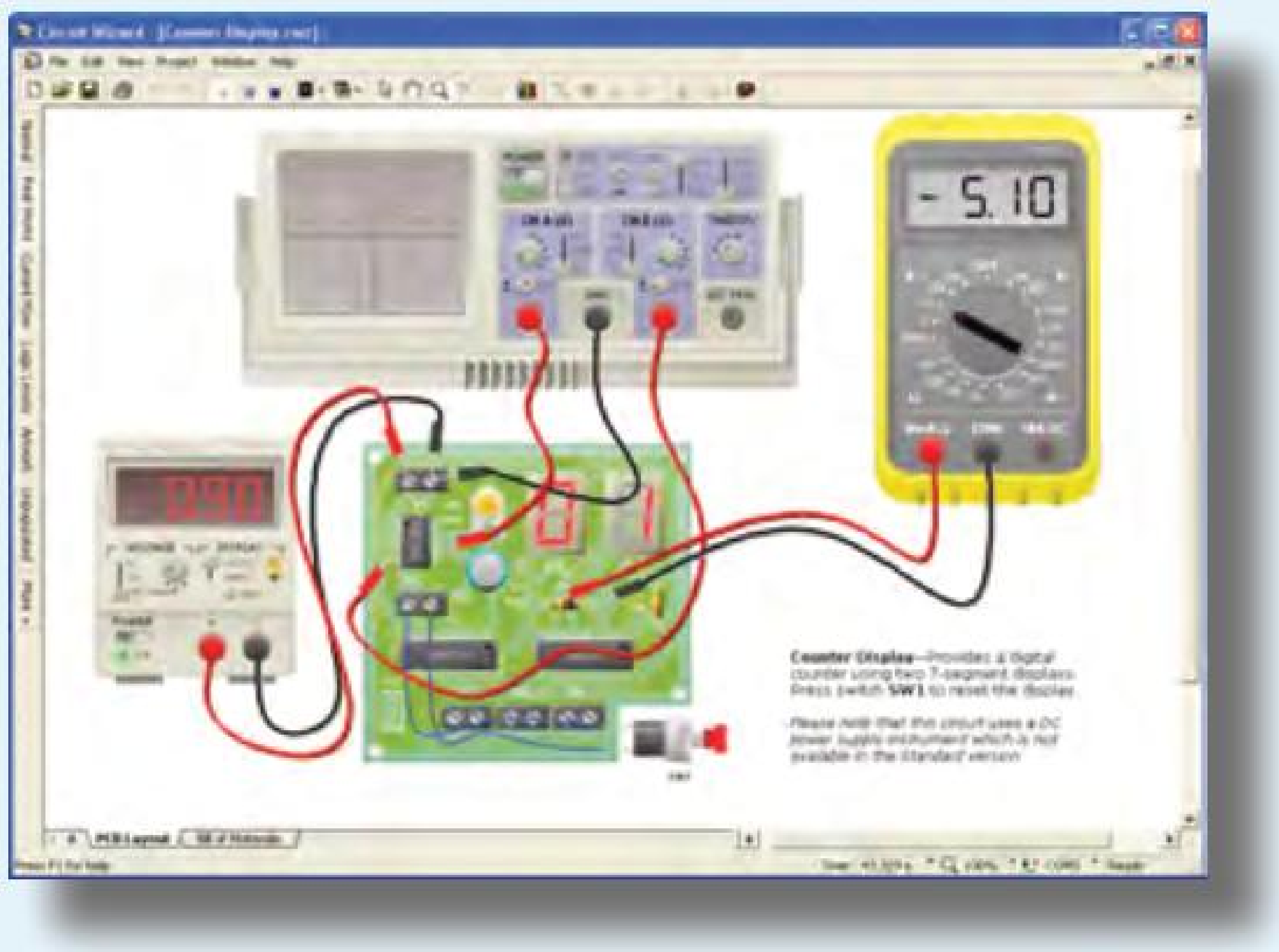

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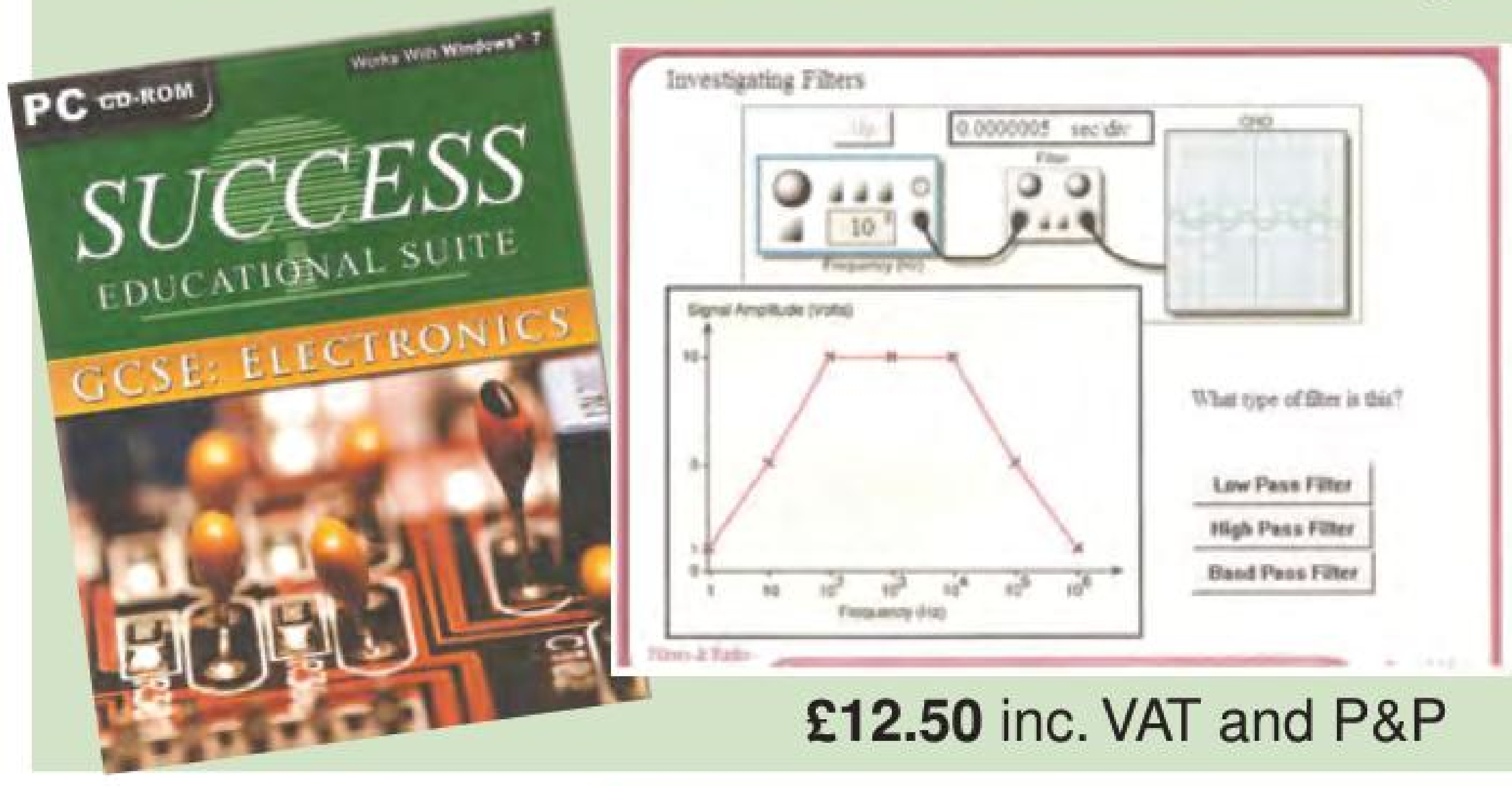

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RPI16IN
from Zeal Electronics

This month, Mike Tooley, our resident Raspberry Pi expert, turns his attention to the RPI16IN, an optically isolated 16-bit digital input board designed for the Raspberry Pi. Like the RPIADCISOL that we reviewed in the December 2014 issue of *EPE*, this board was designed by Dr Stephen Alsop specifically for use in 'harsh' and noisy industrial environments.

The RPI16IN is one of three high-performance, optically isolated interface boards for the Raspberry Pi from Zeal Electronics Ltd. The optical isolation eliminates the problems that would normally be associated with inputs that are at different potentials above or below the ground potential of the Raspberry Pi. This is important in a number of applications – for example, monitoring alarm or machinery contacts, which are at higher potentials above ground or at differing potentials from each other. Furthermore, if the wiring from these needed to be run around a factory alongside other electrically noisy items, then electrical interference would be inserted into the inputs. Without input isolation, the varying potentials of the contacts, the ground loops and the interference could damage or disrupt the operation of the Raspberry Pi. With the RPI16IN board, each input would be individually isolated from the others and so higher potentials and ground loops would be avoided. Also, unwanted noise and interference would be minimised.

The RPI16IN has no less than 16 optically isolated inputs, but if these aren't quite enough for your particular application, up to eight similar boards can be easily daisy-chained (see later) to provide a massive total of 128 optically isolated inputs. Each of the 16 inputs requires a signal voltage of between 3V and 8V, which may be either AC or DC. Voltages in excess of the rated 8V maximum are catered for by placing a resistor in series with the respective input. The RPI16IN can be used with all current and past versions of the Raspberry Pi, including Versions 1 and 2, types A, B and B+, as well as the new single-card industrial Raspberry Pi Compute Module). The board is also compatible with any microprocessor system that has an industry-standard SPI interface.

Optical isolation

As mentioned in our review of the RPIADCISOL (see December 2014 *EPE*) optical isolation of inputs can be instrumental in preventing high voltages from the components being switched or monitored from damaging or interfering with the Raspberry Pi. For example, inputs could be derived from power switching circuits which are several hundred volts above ground.

Without this optical isolation, the Raspberry Pi could easily be destroyed. Isolation considerably reduces the likelihood of impulse voltages and spikes getting back into the Raspberry Pi, which could cause it to crash or be damaged. Isolation is essential whenever sensitive electronic equipment like the Raspberry Pi is used in electrically harsh environments, for example in heavy industry.

The optical isolators used in the RPI16IN are TCMT4600 devices from Vishay. These are high performance, low-profile quad devices with AC input and transistor output. They are rated for an isolation test voltage of 3.75kV RMS, with a coupling capacitance of just 0.3pF. This makes them ideal for high-speed applications. However, due to the limitations of the board layout and its associated components, the quoted isolation voltage (measured between signal input ground and the common 0V supply rail) is 1kV. This should be more than adequate for most applications!

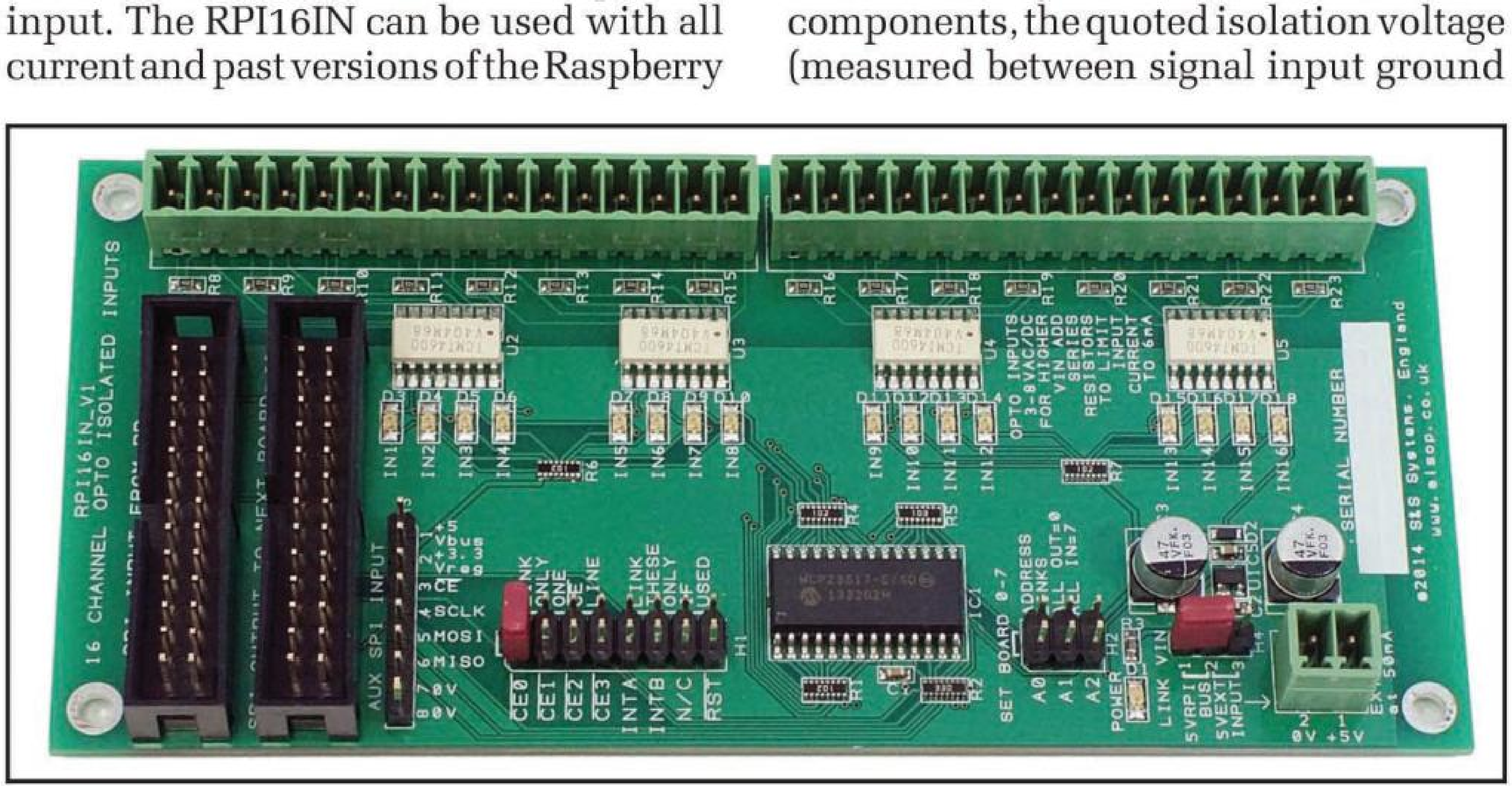

Fig.1. The RPI16IN 16-bit optically isolated input board for the Raspberry Pi

Extending the input signal range

To use the inputs for voltages in excess of the nominal 8V AC/DC it is necessary to place a suitably rated fixed resistance of appropriate value in series with the input. As a rule of thumb, the resistance value can be calculated on the basis of 143Ω for every 1V above the 8V limit. This arrangement is designed to reduce the input current to approximately 7mA. So, for example, if the input voltage V_{in} is 30V, then the required value of input resistance is calculated as follows:

$$R_{in} = (V_{in} - 8) \times 143 = (30 - 8) \times 143$$
$$= 22 \times 143 = 3146\Omega$$

The nearest preferred value of resistor is 3.3kΩ and the required power rating can be calculated from:

$$P = (V_{in} - 8)^2 / R_{in} = 22^2 / 3300$$
$$= 484 / 3300 = 0.15W$$

Hence a fixed resistor of 3.3kΩ rated at ¼W or greater should be perfectly adequate.

Daisy chaining

Up to eight of the same RPI16IN boards can be daisy-chained (see Fig.4) to give 8 × 16 = 128 optically isolated inputs. In this case, the first board will provide inputs 1 to 16, the second board inputs 17 to 32 and so on. Each board will need to have its own unique address within the total address space available. For example, the first board will have address 000, the second 001, and so on. The board address can be set by means of configuration links (see Fig.5).

When daisy chaining multiple RPI16IN boards, it must be borne in mind that, since each board can demand up to 50mA of supply current, so the current drain on the Raspberry Pi's power supply could be excessive. For this reason, a suitably rated external 5V DC supply should be used and the RPI16IN's supply links (see Fig.2) should be set accordingly.

Auxiliary SPI

When using other computers or microprocessors (eg, Microchip PIC

Board specification

Number of inputs	16 optically isolated digital inputs (expandable up to 128 inputs by adding up to seven further boards)
Input voltage	5V nominal, but will operate from 3V to 8V AC or DC (the input voltage can be easily extended by using additional series resistors – see text)
Input current	5mA typical
Input connectors	All inputs use standard 3.5mm industrial plug-in screw terminal connectors arranged in signal/ground pairs
Voltage isolation	1kV max. (see text)
Interface	Standard Raspberry Pi GPIO for digital I/O and high-speed SPI interface with Mode 0,0 and 1,1
Dimensions	60 × 135 mm
Mounting	Four 3mm mounting holes at 52 × 127mm
Bus connector	The Raspberry Pi is connected via a standard 26-way GPIO ribbon connector (compatible with all current versions of the Raspberry Pi, including the Model A, B and B+)
Power supply	+5V at 50mA (may be powered directly from the Raspberry Pi +5V bus or from an external +5V supply – see text)

Listing 1

```
while (1) {  // Loop continuously
    for (c=3;c<10;c++) {      // Read between 3 to 9
      if (RPI16IN_OptoOn(c)) {
        printf("RPI16IN board input %d is ON\n",c);
      }
    }
  }
```

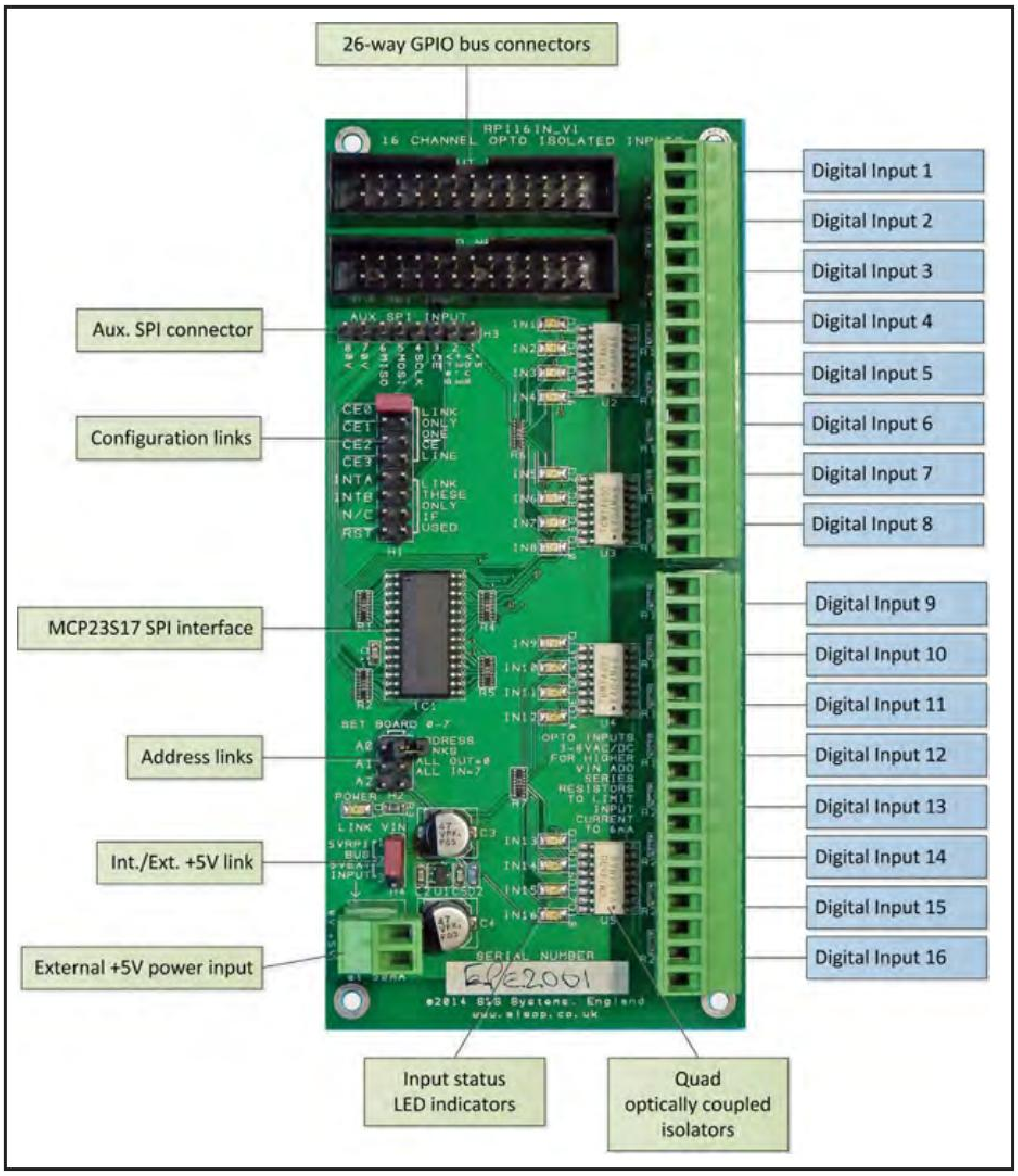
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Fig.2. The RPI16IN board layout

devices) their SPI interfaces can be connected to the RPI16IN's auxiliary SPI connector (see Fig.2). To avoid possible damage to the Raspberry Pi's GPIO port, this header should not be used if the RPI16IN is already connected to a Raspberry Pi.

Documentation and example code

The RPI16IN is supplied with an extensive and well-illustrated 95-page manual that provides full information on installing, connecting, using and programming the range of boards available from Zeal Electronics. The manual assumes that the reader has some familiarity with the C-programming language and, while C is a somewhat more demanding and prescriptive programming language than either BASIC or Python, a simple web search will provide newcomers with access to a vast repository of information, tutorials and example code.

The board is most conveniently programmed using the Raspberry Pi's own built in C compiler, GCC. Leafpad (or an equivalent text editor) will be required to write and edit your C source code, but all of the other files needed in order to compile an executable program are supplied with the RPI16IN. They include all relevant header files, together with a sample C program and an associated make file. The code supplied can be freely used in any non-commercial applications, within education, and for home use as per the standard GNU v2 open-source license. The source code files are efficient and commented in such a way as to make them easy to use and understand, and newcomers to C-programming should have little difficulty in getting to grips with them.

On test

The RPI16IN was tested with a number of different sensors with logic outputs (both TTL and MOS-compatible) and also with switched AC and DC sources of up to 50V. In addition, I applied test voltages of 220V AC and 375V DC connected between the ground of a TTL-compatible square wave signal and the RPI16IN's 0V rail (ground on the Raspberry Pi). At all times the test program operated flawlessly and I noticed absolutely no change in the displayed reading while the test voltage was applied and subsequently removed. During these tests I found the on-board input status LEDs useful – they confirmed that the TTL-compatible input signal was still present.

Developing applications for the RPI16IN is relatively straightforward, and while a working knowledge of C would be a distinct advantage, it is easy to adapt the code supplied with the RPI16IN and develop simple routines for use in your own applications. As an example, the brief code fragment shown in Listing 1 to the left reads and displays the status of inputs 3 to 9.

The code loops and examines each input in turn, starting at input 3 and ending at input 9. The if function returns true if the respective input is found to be ON and a message is displayed indicating which input has become active (note that, if the board is not plugged in, it also returns true). A much more detailed and fully commented example can be found in the software folder provided with the RPI16IN.

Other products from Zeal Electronics

In addition to the RPI16IN, Zeal Electronics also supplies two other high-specification optically isolated interface cards designed specifically for the Raspberry Pi. These boards can all be 'daisy chained' onto the Pi's GPIO bus and can be connected to the 26-way GPIO expansion

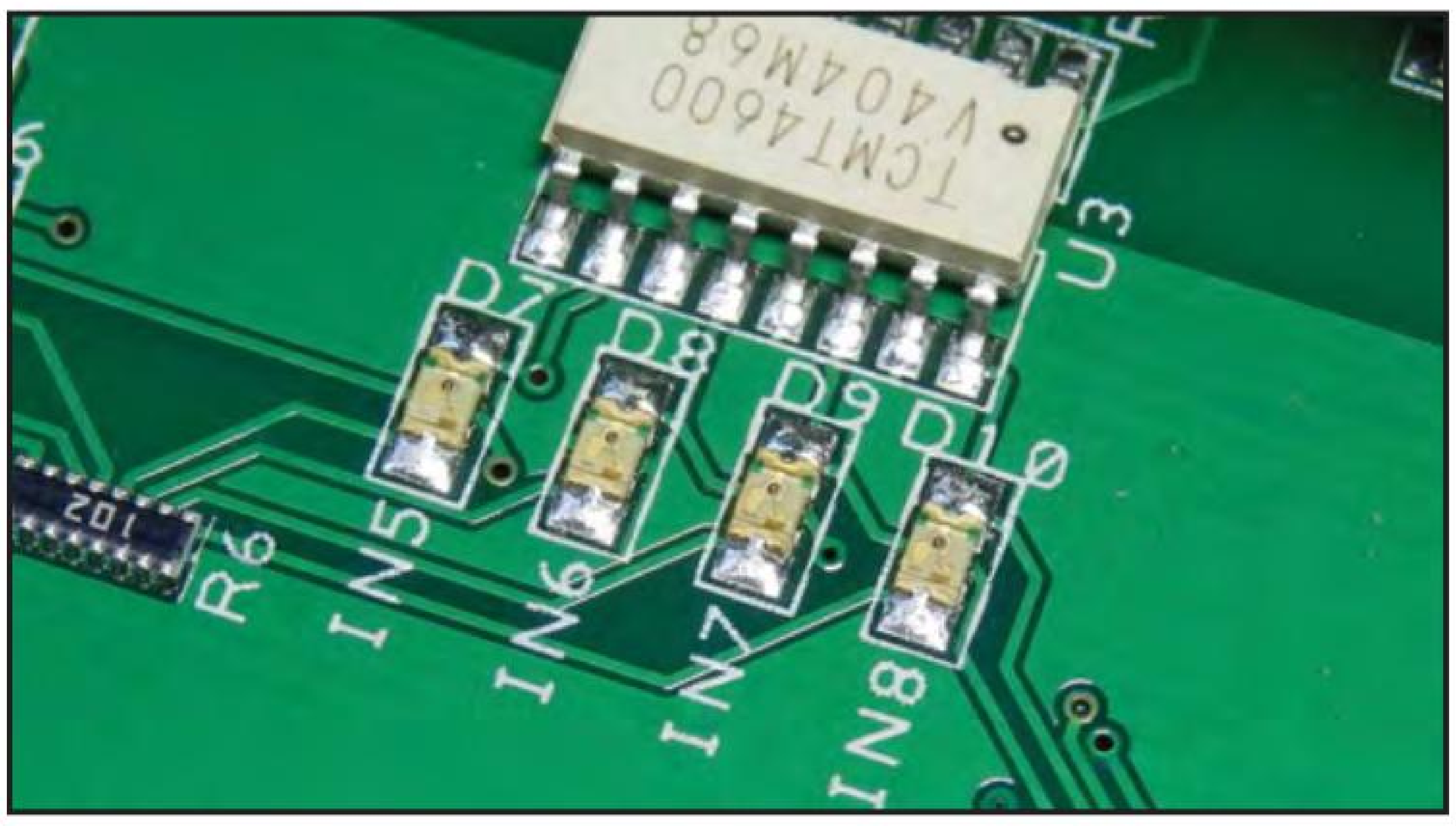


Fig.3. Quad optical isolator with status LEDs

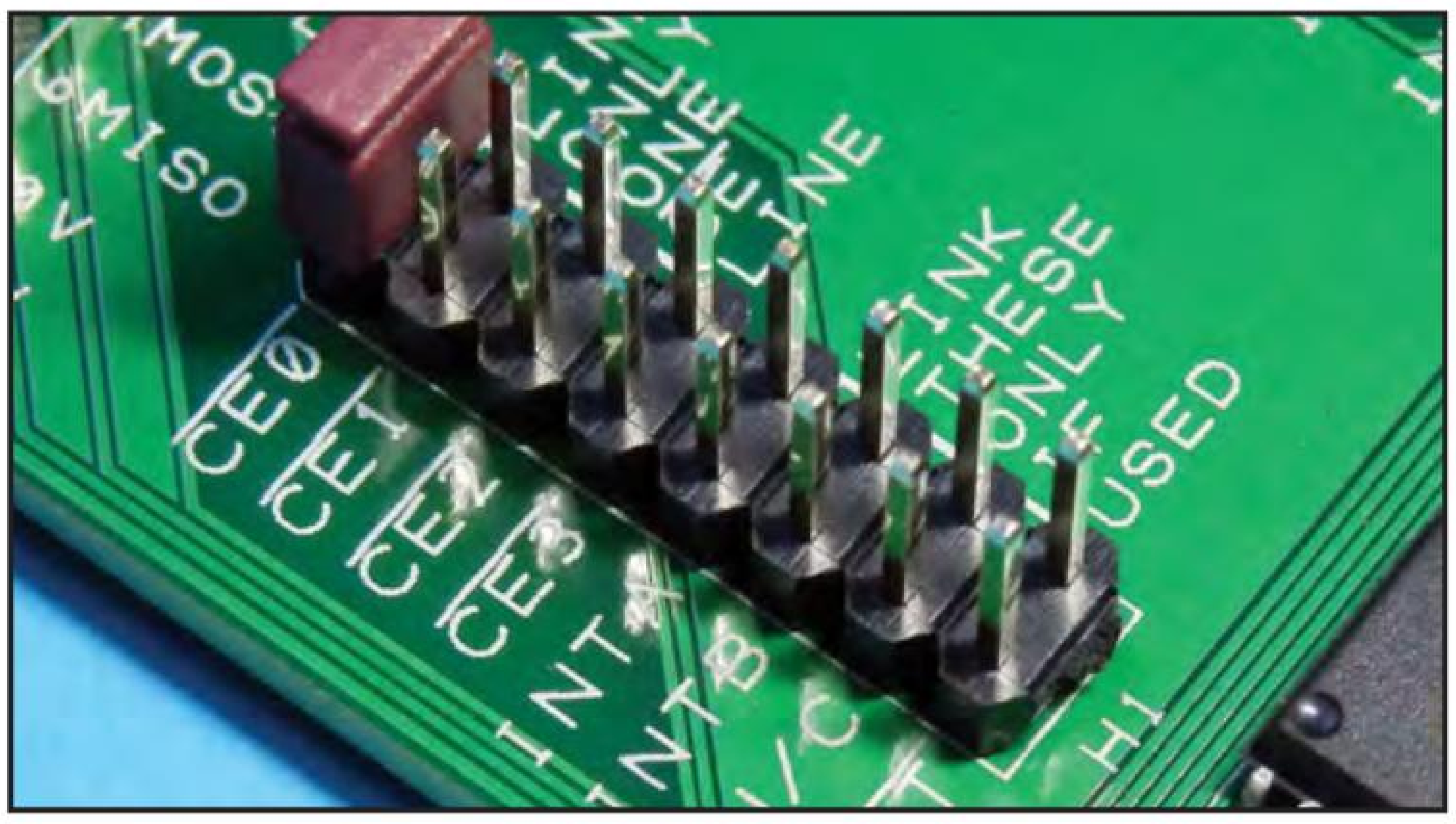


Fig.5. Configuration links used for address selection

connector in order to provide an extended digital I/O capability. We will be taking a detailed look at the companion RPI16OUT interface board in a future issue of *EPE*.

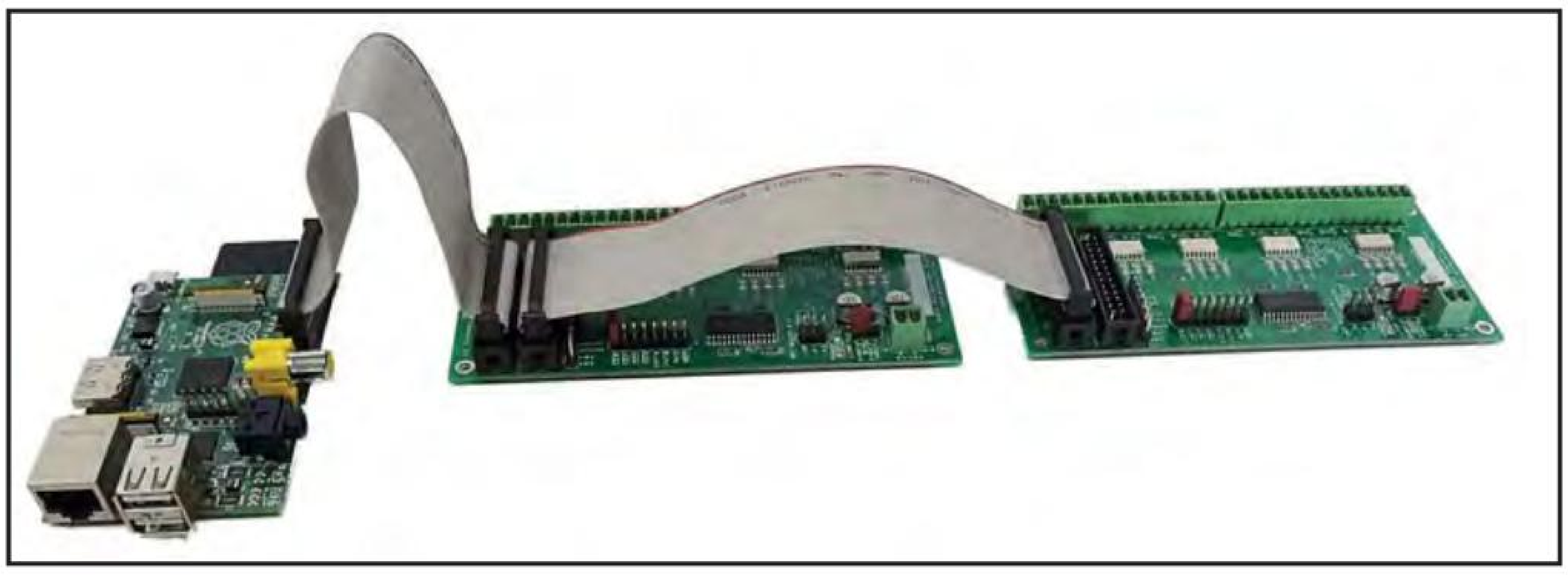


Fig.4. Daisy-chained RPI16IN boards connected to a Raspberry Pi Model B

Pricing

The RPI16IN costs £30 + VAT (10% discount for *EPE* readers). Bearing in mind the advantages of having a high degree of input isolation and the extensive supporting documentation, this represents excellent value for money.

Conclusion

Like the RPIADCISOL that we reviewed last December, this board would be a godsend if you found yourself working in an environment where a very high degree of electrical isolation is needed. But, if that's not the case, the board will still give you the added security of knowing that your Raspberry Pi has been given the benefit of a very high degree of protection from the ravages of the real world.

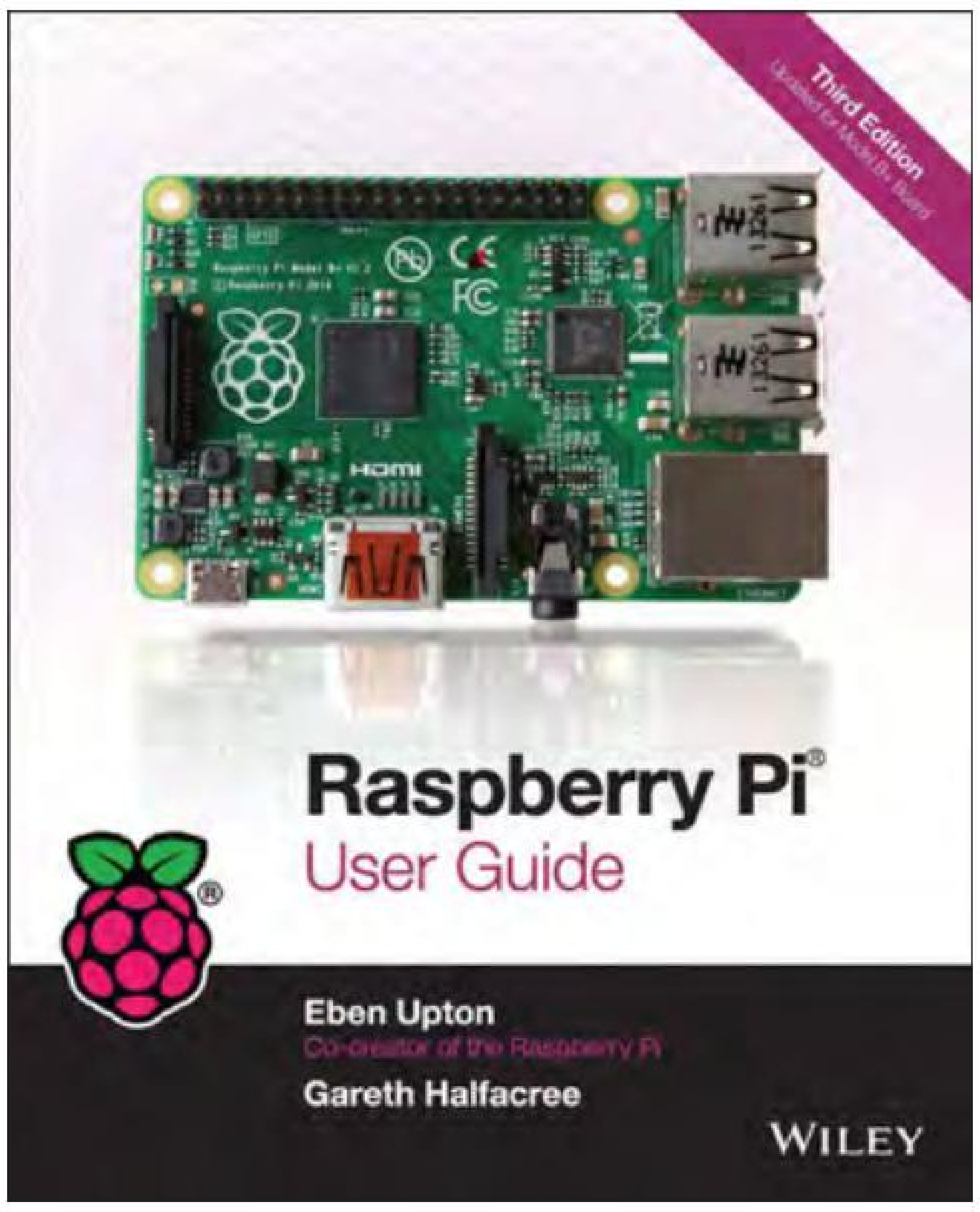
The RPI16IN has an excellent specification and is well supported with liberally commented source code. Under test, the board performed very well and readers with limited C-programming experience should be able to get the board up and running quickly and easily. The interface is good value and can be highly recommended for use in applications where input sensors and transducers are not at true ground potential.

Raspberry Pi User Guide (Third Edition)

Mike Tooley reviews a key Raspberry Pi design book and user guide

This popular book has been revised, updated and expanded with an extra 50 or so pages. The book aims to tell you everything you need to know to get your Raspberry Pi fully operational. The Third Edition has 17 chapters (compared with 13 in the First Edition) and three useful appendices. The book's four main parts deal with: connecting the board; the Pi as a media centre and web server; programming with Scratch and Python; and expanding the Pi's I/O capability.

With a mixture of hardware- and software-related content there is something in the book for everyone. The book has some extremely useful chapters on the mysteries of Linux system administration, software configuration, troubleshooting, network configuration and connecting to a wireless network. For most of us 'died-in-the-wool' electronics enthusiasts, these topics must surely represent the 'collected black arts' of getting a microcomputer system up and running! Less useful, at least for regular *EPE* Readers, is the chapter entitled 'Learning to Hack Hardware' which provides a very basic introduction to electronic components and soldering. That said, this particular chapter will be invaluable to anyone with no previous experience of electronics.



The book's authors have a considerable pedigree, and both have extensive experience of developing open hardware projects. Eben Upton is a founder of the Raspberry Pi Foundation and currently serves as the CEO of Raspberry Pi (Trading), its commercial arm. Formerly a system administrator working in the education sector, Gareth Halfacre is a freelance technology journalist. So, if you wanted to hear it from the horse's mouth you couldn't get much closer than this.

The Third Edition has been expanded to include the recently introduced Raspberry Pi Model B+. For most readers nowadays this is likely be an entry-level purchase and its inclusion in the book is, therefore, very timely. The Third Edition also includes a completely new chapter on the Raspberry Pi Software Configuration Tool. This chapter should be essential reading for anyone needing to get the best of the functionality provided by this extremely powerful software tool. The chapter describes each of the options provided by the tool and explains, in very understandable terms, what happens when the choices are implemented. Crucially, the chapter warns about the dangers of overclocking and the problems that might occur if the advice is ignored.

At a published price of £14.99 (£16.99 including P&P) from *EPE Book Service* – see below) this book represents excellent value. So, if you are about to take the plunge into the world of Raspberry Pi, then this book could be a really useful investment.

Book details

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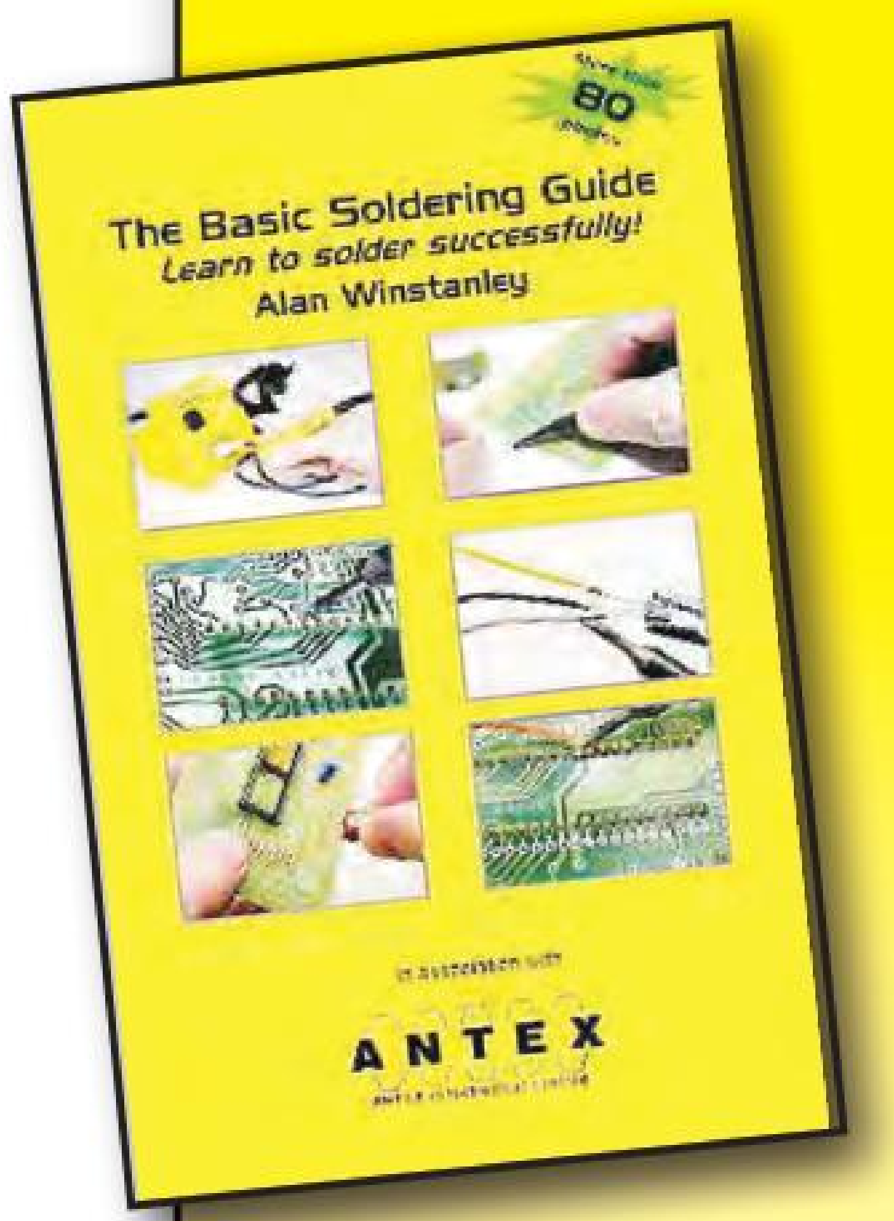

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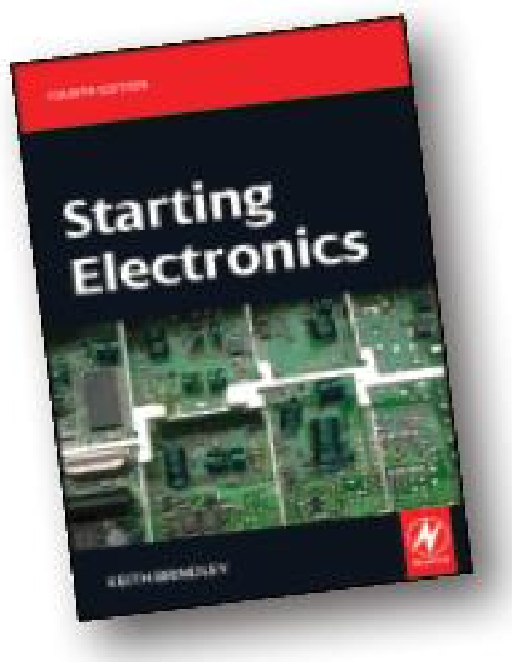

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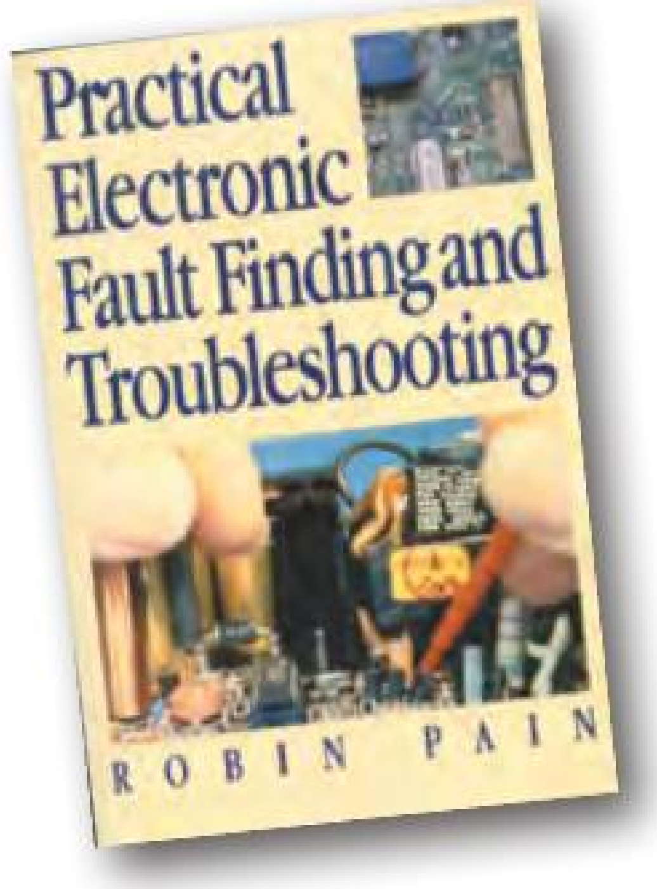

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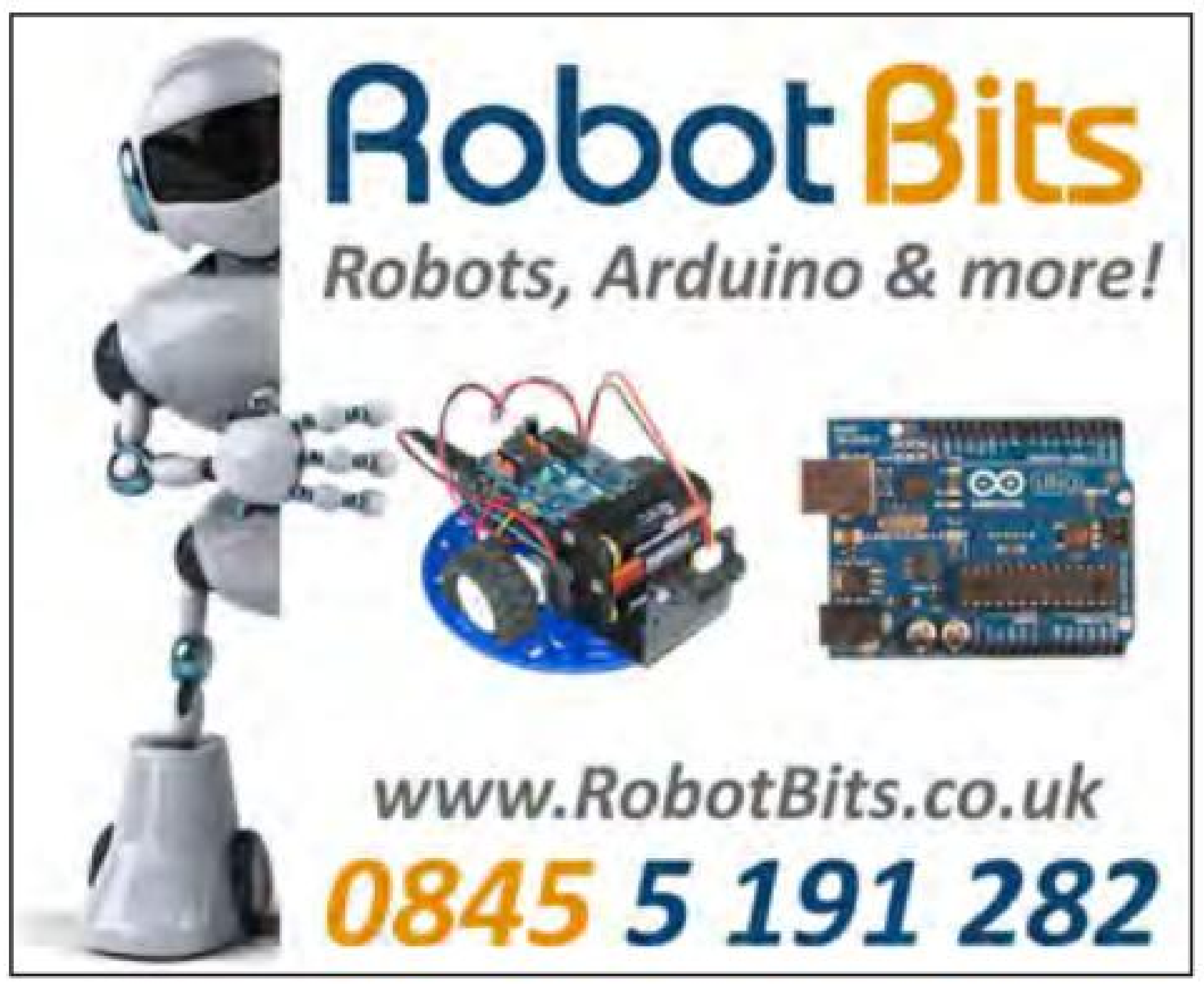

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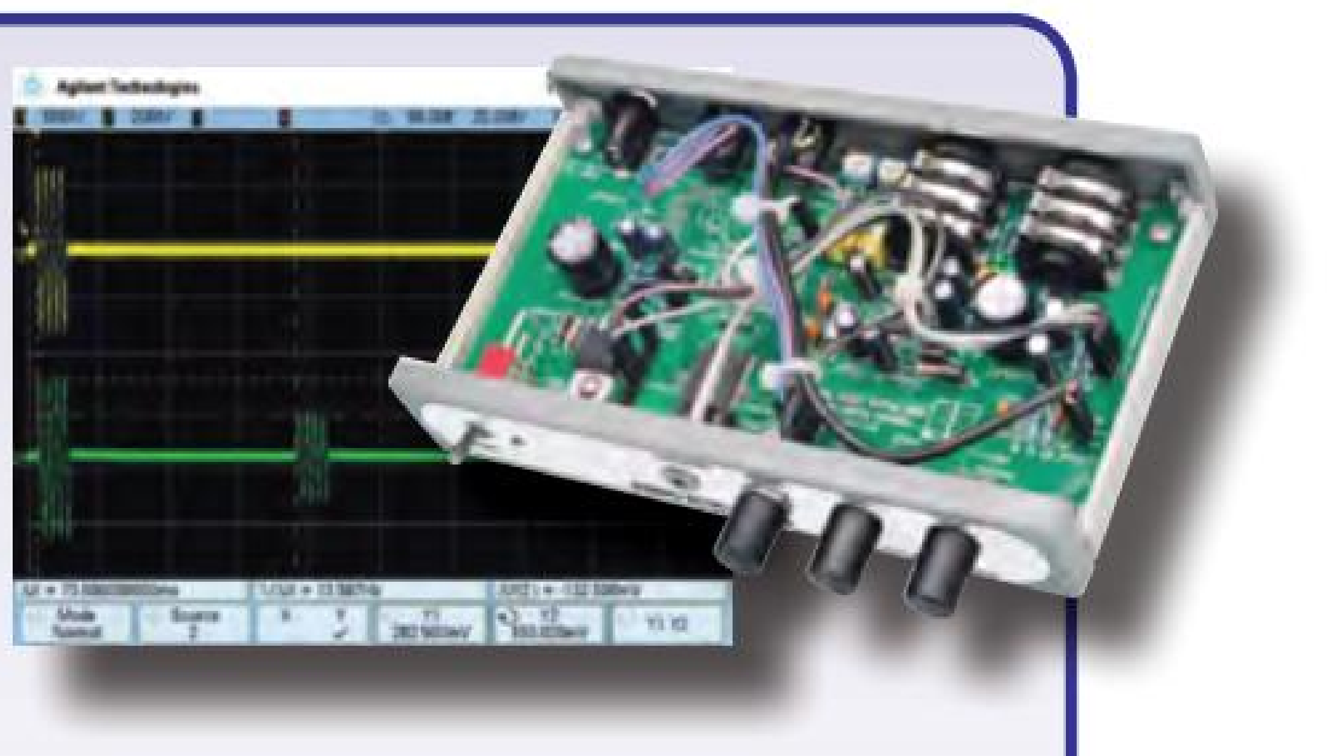
Next Month



Stereo Echo & Reverb Unit

Based on the *Stereo Audio Delay* featured in the February 2015 issue, this modified unit can be used to provide adjustable echo or reverberation for recording or public address (PA) work. By using revised software and slight changes to the circuitry, we show how the same hardware can provide these different functions. We'll also describe some extra features that can be useful in either mode.

10A/230V Speed Controller for Universal Motors – Part 1

Most mains motor speed controllers aren't very good! They often have very poor low-speed control or won't allow control right up to the motor's maximum speed. Here's one that is exceptional: a microcontroller-powered full-wave circuit that overcomes both these problems with smooth control. It's ideal for electric drills, lawn edgers, circular saws, routers or any other appliance with universal (ie, 'brush-type') motors.

"Tiny Tim" Stereo Amplifier – Part 3

In this final instalment we finish building the *Tiny Tim Stereo Amplifier* by fitting all the modules into the case and wiring it up. We'll also look at testing the unit, its final performance and some other useful tidbits.

Teach-In 2015

In next month's *Teach-In 2015*, we will show you how we used our favourite software applications, TINA and Circuit Wizard, to design, analyse and construct the pre-amplifier module. We will also show how the project can be configured for use in a variety of different applications. To help you with this, we will introduce some powerful virtual instruments.

MARCH '15 ISSUE ON SALE 5 FEBRUARY 2015

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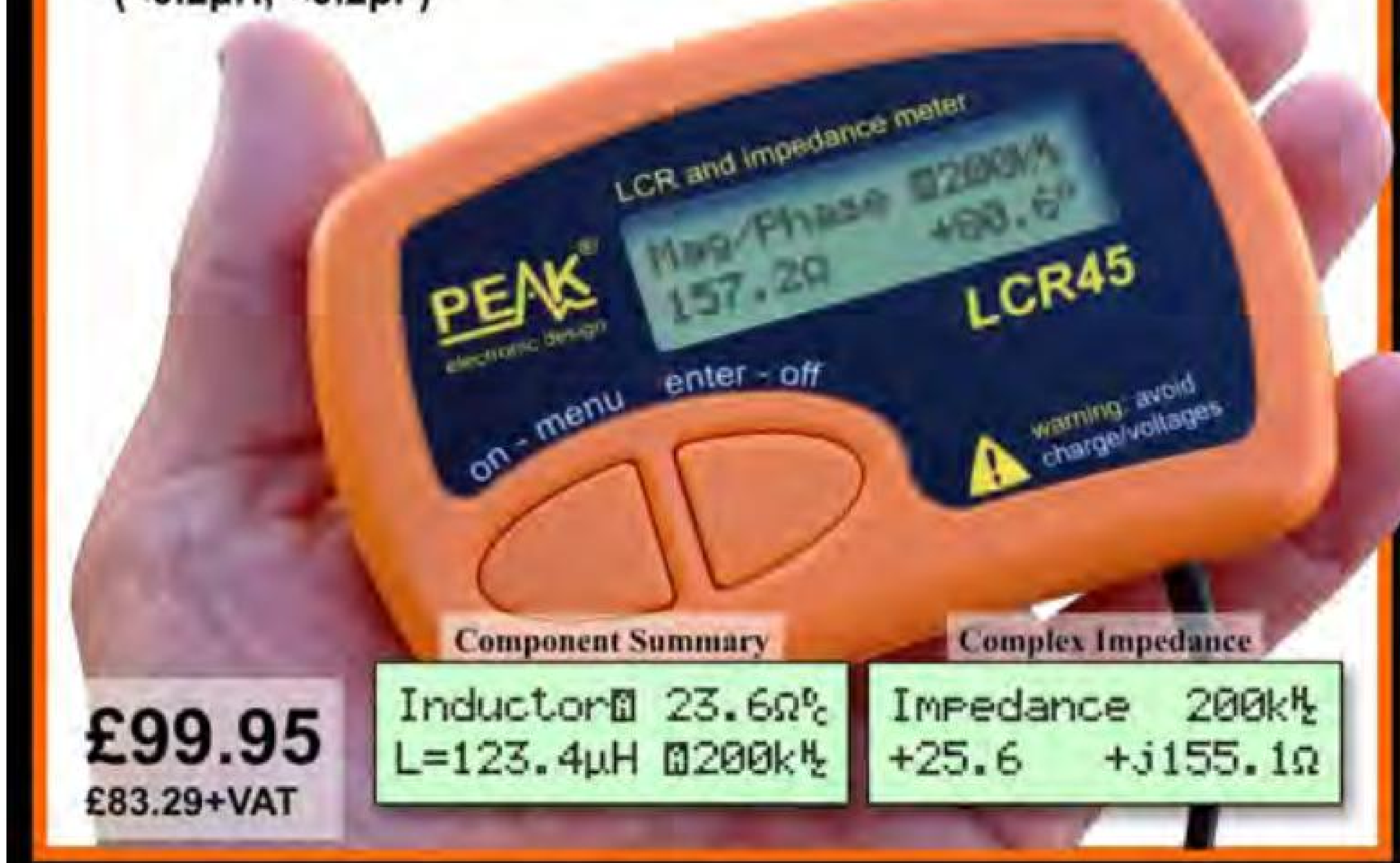

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